

**FINAL OPERABLE UNIT 1
REMEDIAL INVESTIGATION REPORT
PUCHACK WELL FIELD SUPERFUND SITE
REMEDIAL INVESTIGATION/
FEASIBILITY STUDY (RI/FS)
PENNSAUKEN TOWNSHIP, NEW JERSEY
Work Assignment No.: 102-RICO-02JL
Volume I of II**

Prepared for:
U.S. Environmental Protection Agency
290 Broadway
New York, New York 10007-1866

Prepared by:
CDM Federal Programs Corporation
125 Maiden Lane - 5th Floor
New York, New York 10038

EPA Work Assignment No.	: 102-RICO-02JL
EPA Region	: II
Contract No.	: 68-W-98-210
CDM Federal Programs Corporation DCN:	: 3223-102-RT-RIRT-05395
Prepared by	: CDM Federal Programs Corporation
Site Manager	: Frank Tsang
Telephone Number	: (212) 785-9123
EPA Remedial Project Manager	: Jonathan Gorin
Telephone Number	: (212) 637-4361
Date Prepared	: June 22, 2005

**FINAL OPERABLE UNIT 1
REMEDIAL INVESTIGATION REPORT
PUCHACK WELL FIELD SUPERFUND SITE
REMEDIAL INVESTIGATION/
FEASIBILITY STUDY (RI/FS)
PENNSAUKEN TOWNSHIP, NEW JERSEY
Work Assignment No.: 102-RICO-02JL
Volume II of II**

Prepared for:
U.S. Environmental Protection Agency
290 Broadway
New York, New York 10007-1866

Prepared by:
CDM Federal Programs Corporation
125 Maiden Lane - 5th Floor
New York, New York 10038

EPA Work Assignment No.	: 102-RICO-02JL
EPA Region	: II
Contract No.	: 68-W-98-210
CDM Federal Programs Corporation DCN:	: 3223-102-RT-RIRT-05395
Prepared by	: CDM Federal Programs Corporation
Site Manager	: Frank Tsang
Telephone Number	: (212) 785-9123
EPA Remedial Project Manager	: Jonathan Gorin
Telephone Number	: (212) 637-4361
Date Prepared	: June 22, 2005

TABLE OF CONTENTS

Executive Summary	ES-1
1.0 Introduction	1-1
1.1 Purpose of the Report	1-1
1.2 Site Description	1-2
1.3 Site History	1-3
1.4 Report Organization	1-5
2.0 Study Area Investigations	2-1
2.1 Contaminant Source Investigations	2-2
2.2 Meteorological Investigations	2-2
2.3 Geological and Hydrogeological Investigations	2-2
2.3.1 Overview	2-2
2.3.2 Deep Pilot Borehole Advancement	2-4
2.3.3 Subsurface Soil and Aquifer Sediment Sampling	2-4
2.3.3.1 Subsurface Soil and Aquifer Sediment Sampling for Lithologic Characterization	2-4
2.3.3.2 Subsurface Soil Sampling for Chemical Analysis	2-5
2.3.3.3 Soil Sample Identifiers	2-6
2.3.4 Downhole Geophysical Logging	2-8
2.3.5 Monitoring Well Installation and Development	2-10
2.3.5.1 Monitoring Well Borehole Backfilling	2-10
2.3.5.2 Monitoring Well Installation	2-11
2.3.5.3 Monitoring Well Development	2-12
2.3.6 Groundwater Sampling	2-12
2.3.6.1 Selection of Monitoring Wells for Groundwater Sampling ...	2-13
2.3.6.2 Groundwater Sample Collection Procedures	2-13
2.3.6.3 Groundwater Sample Chemical Analysis	2-14
2.3.6.4 Groundwater Sample Identifiers	2-15
2.3.7 Quality Assurance/Quality Control Sampling	2-17
2.3.7.1 Soil and Aquifer Sediment Sampling QA/QC Samples	2-17
2.3.7.2 Groundwater Sampling QA/C Samples	2-18
2.3.8 Water Level Measurements	2-19
2.3.8.1 Synoptic Water Level Measurements	2-20
2.3.8.2 Continuous Water Level Measurements	2-21
2.3.9 Monitoring Well Location and Elevation Survey	2-21
2.3.10 Control of Investigation-derived Wastes	2-22
2.4 Demography and Land Use Surveys	2-22
3.0 Physical Characteristics of the Study Area	3-1
3.1 Topography	3-1
3.2 Meteorology	3-1
3.3 Surface Water Hydrology	3-1

TABLE OF CONTENTS (Continued)

3.4	Regional Geology and Hydrogeology	3-2
3.4.1	Regional Geology	3-2
3.4.2	Regional Hydrogeology	3-2
3.5	Site Geology and Hydrogeology	3-3
3.5.1	Site Soils and Geology	3-3
3.5.2	Site Hydrogeology	3-4
	3.5.2.1 Hydrostratigraphic Framework	3-5
	3.5.2.2 Groundwater Levels and Flow	3-8
3.6	Demographics and Land Use	3-11
4.0	Occurrence and Distribution of Contaminants in Soils, Aquifer Sediments, and Groundwater	4-1
4.1	Introduction	4-1
4.1.1	Screening Criteria	4-1
4.1.2	Background Concentrations of Constituents Identified as Contaminants	4-2
	4.1.2.1 Soils and Aquifer Sediments	4-2
	4.1.2.2 Groundwater	4-3
4.1.3	Quality Assurance/quality Control	4-3
	4.1.3.1 Soil and Aquifer Sediment Samples	4-3
	4.1.3.2 Groundwater Samples	4-4
4.2	Extent and Nature of Contamination in Soils from Five Industrial/commercial Properties	4-5
4.2.1	Advance Process Supply Property	4-6
	4.2.1.1 Inorganic Contamination	4-6
	4.2.1.2 Organic Contamination	4-6
4.2.2	King Arthur Property	4-6
	4.2.2.1 Inorganic Contamination	4-6
	4.2.2.2 Organic Contamination	4-7
4.2.3	Mercon Property	4-8
	4.2.3.1 Inorganic Contamination	4-8
	4.2.3.2 Organic Contamination	4-8
4.2.4	SGL Chrome Property	4-8
	4.2.4.1 Inorganic Contamination	4-8
	4.2.4.2 Organic Contamination	4-9
4.2.5	Supertire Property	4-10
	4.2.5.1 Inorganic Contamination	4-10
	4.2.5.2 Organic Contamination	4-11
4.3	Extent and Nature of Contamination in Aquifer Sediments	4-11
4.3.1	Inorganic Contamination	4-11
4.3.2	Organic Contamination	4-12
4.4	Extent and Nature of Contamination in Groundwater	4-13
4.4.1	Chromium Contamination	4-13
	4.4.1.1 Upper Aquifer	4-14

TABLE OF CONTENTS (Continued)

4.4.1.2	Middle Aquifer	4-14
4.4.1.3	Intermediate Sand	4-15
4.4.1.4	Lower Aquifer	4-16
4.4.2	Organic Contaminants	4-17
4.4.2.1	Upper Aquifer	4-17
4.4.2.2	Middle Aquifer	4-17
4.4.2.3	Intermediate Sand	4-18
4.4.2.4	Lower Aquifer	4-19
4.4.3	Other Contaminants and Constituents in Groundwater	4-20
4.4.3.1	Cadmium, Lead, and Mercury	4-20
4.4.3.2	Iron and Manganese	4-21
4.4.3.3	Ammonia, Nitrite, and Nitrate	4-22
4.4.3.4	Chloride, Sulfate, and pH	4-22
4.4.4	Changes in Contaminant Levels with Time	4-23
4.4.4.1	Chromium	4-23
4.4.4.2	Organic Contaminants	4-24
4.5	Potential Sources of Contamination	4-24
4.5.1	Advance Process Supply Property	4-25
4.5.1.1	Chromium	4-25
4.5.1.2	Organic Contaminants	4-25
4.5.2	Davidson Pacific Wood Products Property	4-25
4.5.2.1	Chromium	4-25
4.5.2.2	Organic Contaminants	4-26
4.5.3	King Arthur Property	4-26
4.5.3.1	Chromium	4-26
4.5.3.2	Organic Contaminants	4-27
4.5.4	Mercon Property	4-27
4.5.4.1	Chromium	4-27
4.5.4.2	Organic Contaminants	4-27
4.5.5	SGL Chrome Property	4-27
4.5.5.1	Chromium	4-27
4.5.5.2	Organic Contaminants	4-29
4.5.6	Supertire Property	4-29
4.5.6.1	Chromium	4-29
4.5.6.2	Organic Contaminants	4-29
4.5.7	Summary of Potential VOC Sources and Hot Spots	4-30
5.0	Contaminant Fate and Transport	5-1
5.1	Inorganic Contaminants	5-1
5.1.1	Chromium Chemistry	5-1
5.1.1.1	Introduction	5-1
5.1.1.2	Relation of Chromium to Other Constituents in Groundwater	5-2
5.1.2	Fate of Chromium in Groundwater	5-3

TABLE OF CONTENTS (Continued)

5.1.2.1	Advection, Dispersion, and Dilution	5-4
5.1.2.2	Adsorption	5-5
5.1.2.3	Chemical Reduction	5-6
5.1.2.4	Evidence for Natural Attenuation of Chromium in Groundwater	5-7
5.1.3	Transport of Chromium in the Aquifer System	5-7
5.1.3.1	Site Conceptual Model	5-7
5.1.3.2	Current Transport of Chromium	5-10
5.2	Organic Contaminants	5-10
5.2.1	Reactions Involving Volatile Organic Compounds in Groundwater	5-10
5.2.2	Fate of Volatile Organic Compounds in Groundwater	5-12
5.2.2.1	Changes in Concentrations of Volatile Organic Compounds	5-13
5.2.2.2	The Geochemical Environments of Groundwater Containing Volatile Organic Compounds	5-13
5.2.2.3	Evidence for Natural Attenuation of Volatile Organic Compounds in Groundwater	5-14
5.2.3	Transport of Volatile Organic Compounds in the Aquifer System	5-15
5.2.3.1	Contributions from Sources of Volatile Organic Compounds	5-16
5.2.3.2	Historical Transport Mechanism of Organic Contaminants	5-16
5.2.3.3	Current Transport Mechanism for Volatile Organic Compounds	5-17
5.3	Interactions Between Inorganic and Organic Contaminants	5-18
6.0	Human Health Risk Assessment	6-1
7.0	Summary and Conclusions	7-1
7.1	Hydrogeology	7-1
7.2	Nature and Extent of Contamination	7-1
7.2.1	Inorganic Contamination in Groundwater	7-1
7.2.2	Organic Contamination in Groundwater	7-2
7.2.3	Potential Contamination Sources	7-2
7.3	Conclusions	7-3
7.4	Recommendations	7-3
8.0	References	8-1

LIST OF APPENDICES (in Volume II)

Appendix A	Field Change Request Forms
Appendix B	OU1 RI Monitoring Well Boring Logs and Well Development Field Notes
Appendix C	Geophysical Logs
Appendix D	OU1 RI Monitoring Well Construction Diagrams
Appendix E	Aquifer System Structure-Contour Maps
Appendix F	Soil and Aquifer Sediment Sample Data
Appendix G	Groundwater Sample Data: 1999 and 2000-2001

Adobe Acrobat Reader is required to view Appendices C, E, F and G, double click on the file called “adbeRdr70_enh_full.exe ” on the CD to install Acrobat Reader if necessary or download the software from the Adobe website (www.adobe.com).

LIST OF FIGURES

Figure 1-1	Puchack Well Field Location
Figure 1-2	OU1 Boundary and Chromium Groundwater Quality Data
Figure 2-1	Monitoring Wells installed During the OU1 RI
Figure 2-2	Location of Wells Used for Synoptic Water-level Measurements in the Potomac-Raritan-Magothy Aquifer System
Figure 2-3	Location of Wells from Which Water Quality Samples Were Collected During 1999-2001
Figure 3-1	Five-layer and Subdivided Interpretations of the Hydrostratigraphic Framework of the Potomac-Raritan-Magothy Aquifer System
Figure 3-2	Estimated Lateral Extent of Minor Sand and Clay Units Within the Potomac-Raritan-Magothy Aquifer System, Section A-A'
Figure 3-3	Location of Wells Used to Describe the Hydrostratigraphic Framework of the Potomac-Raritan-Magothy Aquifer System
Figure 3-4	Potentiometric Heads of the Upper Aquifer, Potomac-Raritan-Magothy Aquifer System, April 2001
Figure 3-5	Potentiometric Surface of the Middle Aquifer, Potomac-Raritan-Magothy Aquifer System, April 2001
Figure 3-6	Potentiometric Surface of the Lower Aquifer, Including the Intermediate Sand Potomac-Raritan-Magothy Aquifer System, April 2001
Figure 4-1	Overview of Soil Boring Locations: APS, King Arthur, Mercon, SGL, and Supertire Properties
Figure 4-2	REAC Soil Borings, APS Property
Figure 4-3	Total Chromium Concentrations as a Function of Iron Concentrations in Soils from the Advance Process Supply Property
Figure 4-4	ERT Soil Borings, King Arthur Property
Figure 4-5	ERT and REAC Soil Borings, Mercon Property
Figure 4-6	Ert Soil Borings, SGL Modern Hard Chrome Property
Figure 4-7	Total and Hexavalent Chromium Concentrations with Depth in Soils and Aquifer Sediments from the SGL Chrome Property
Figure 4-8	Volatile Organic Compound Concentrations with Depth in Soils and Aquifer Sediments from the SGL Chrome Property
Figure 4-9	ERT Soil Borings and REAC Soil Gas Locations, Supertire Property
Figure 4-10	Concentration of 1,1,1-trichloroethane with Depth in Soils and Aquifer Sediments from Boring 09 at the Supertire Property
Figure 4-11	Ratio of Hexavalent Chromium to Total Chromium as a Function of Total Chromium Concentration in Aquifer Sediments from Well Bores
Figure 4-12	Aerial Extent of Metals Exceeding Maximum Contaminant Levels and Action Levels in Groundwater from the Potomac-Raritan-Magothy Aquifer System, 1999-2001
Figure 4-13	Aerial Extent of Chromium Contaminated Groundwater in the Middle Aquifer, 1999-2001
Figure 4-14	Aerial Extent of Chromium Contaminated Groundwater in the Intermediate Sand, 1999-2001

LIST OF FIGURES (Continued)

Figure 4-15	Aerial Extent of Chromium Contaminated Groundwater in the Lower Aquifer, 1999-2001
Figure 4-16	Aerial Extent of Volatile Organic Compounds Exceeding Maximum Contaminant Levels in Groundwater from the Potomac-Raritan-Magothy Aquifer System, 1999-2001
Figure 4-17	Volatile Organic Compound Hot Spot Locations
Figure 4-18	Aerial Extent of Volatile Organic Compound Contaminated Groundwater in the Middle Aquifer, 1999-2001
Figure 4-19	Aerial Extent of Volatile Organic Compound Contaminated Groundwater in the Intermediate Sand, 1999-2001
Figure 4-20	Aerial Extent of Volatile Organic Compound Contaminated Groundwater in the Lower Aquifer, 1999-2001
Figure 4-21	Iron Concentrations in Water from the Middle Aquifer, 1999-2001
Figure 4-22	Iron Concentrations in Water from the Intermediate Sand, 1999-2001
Figure 4-23	Iron Concentrations in Water from the Lower Aquifer, 1999-2001
Figure 4-24	Manganese Concentrations in Water from the Middle Aquifer, 1999-2001
Figure 4-25	Manganese Concentrations in Water from the Intermediate Sand, 1999-2001
Figure 4-26	Manganese Concentrations in Water from the Lower Aquifer, 1999-2001
Figure 4-27	pH in Water from the Middle Aquifer, 1999-2001
Figure 4-28	pH in Water from the Intermediate Sand, 1999-2001
Figure 4-29	pH in Water from the Lower Aquifer, 1999-2001
Figure 4-30	Changes in Concentrations of Chromium, Iron, Manganese, Sulfate and Dissolved Oxygen in Water from Three Wells, 1998-2000
Figure 5-1	Dissolved Oxygen Concentrations in Water from the Middle Aquifer, 1999-2001
Figure 5-2	Dissolved Oxygen Concentrations in Water from the Intermediate Sand, 1999-2001
Figure 5-3	Dissolved Oxygen Concentrations in Water from the Lower Aquifer, 1999-2001
Figure 5-4	Total Chromium Concentrations as a Function of Sulfate Concentrations in Groundwater from the Potomac-Raritan-Magothy Aquifer System
Figure 5-5	Extent of Chromium Plumes in the Lower Aquifer and Intermediate Sand (1999-2001) Superimposed on Potentiometric Surface Map (April 2001) with Groundwater Flow Directions in the Lower Aquifer Identified
Figure 5-6	Concentrations of Total Chromium in Groundwater of the Potomac-Raritan-Magothy Aquifer System along Section A-A', 1999 - 2001

LIST OF TABLES

Table 2-1	Summary of Field Investigation Activities
Table 2-2	Summary of Proposed and Installed Monitoring Well Locations
Table 2-3	Records of EPA/USGS Potomac-Raritan-Magothy Aquifer System Water Supply Well and Monitoring Well Network
Table 2-4	Monitoring Well Pilot Boring Soil and Aquifer Sediment Sample Information
Table 2-5	Monitoring Well Construction Details
Table 2-6	Monitoring Well Borehole Backfill Details
Table 2-7	Monitoring Well Development Data
Table 2-8	Groundwater Sample Locations: October 1999 - December 1999
Table 2-9	Groundwater Sample Information: August 2000 - April 2001
Table 2-10	Minimum Reporting Limits for Inorganic Analytes
Table 2-11	Comparison of Volatile Organic Analysis Method Parameter Lists
Table 2-12	Groundwater Elevation Data - OU1 Remedial Investigation
Table 2-13	Well Surveying Data
Table 3-1	Climatic Data for the Vicinity of Puchack Well Field - OU1 Remedial Investigation
Table 3-2	Mineralogy of Selected Sediment Samples from the Potomac-Raritan- Magothy Aquifer System
Table 3-3	Hydrostratigraphic Framework Data
Table 3-4	Description of Monitoring Wells Selected for Preparation of Hydrographs - OU1 Remedial Investigation
Table 4-1	Soil Screening Criteria for Organic and Inorganic Compounds
Table 4-2	Groundwater Screening Criteria for Organic and Inorganic Compounds
Table 4-3	Selected Surface Soil Sample Results at Four Properties
Table 4-4	Selected Subsurface Soil Sample Results at Four Properties
Table 4-5	Hexavalent and Total Chromium Concentrations in Aquifer Sediments
Table 4-6	Comparison of OU1 Remedial Investigation Groundwater Sample VOC Results to New Jersey Maximum Contaminant Levels
Table 4-7	Changes in Chromium Concentrations in Selected Wells Sampled in 1998-1999, 2000, and 2001
Table 4-8	Changes in VOCs Over Time in Selected Groundwater Samples
Table 5-1	Site Specific Soil/Water Partition Coefficient and Retardation Factor Estimates

LIST OF PLATES

- | | |
|---------|--|
| Plate 1 | Location of Water-Supply and Monitoring Wells Screened in the Potomac-Raritan-Magothy Aquifer System in the Vicinity of the Puchack Well Field Superfund Site, Pennsauken Township, New Jersey |
| Plate 2 | Hydrostratigraphic Sections Through the Potomac-Raritan-Magothy Aquifer System in the Vicinity of the Puchack Well Field Superfund Site, Pennsauken Township, New Jersey |
| Plate 3 | Hydrographs of Water Level Monitoring Wells in the Potomac-Raritan-Magothy Aquifer System in the Vicinity of the Puchack Well Field Superfund Site, Pennsauken Township, New Jersey |

LIST OF ACRONYMS

APS	Advance Process Supply
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylene
CCWD	Camden City Water Department
CDM	Camp Dresser McKee
cis-1,2-DCE	cis-1,2-dichloroethene
CLP	Contract Laboratory Program
CO ₂	carbon dioxide
Cr (III)	trivalent chromium
Cr (VI)	hexavalent chromium
1,2-DCA	1,2-dichloroethane
DCE	dichloroethene
1,1-DCE	1,1-dichloroethene
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DOC	dissolved organic carbon
Eh	oxidation/reduction potential
EMDS	Environmental Management and Data Services
EMSL	Electron Microscopy Services Laboratory
EPA	United States Environmental Protection Agency
ERT	Environmental Response Team
°F	Fahrenheit
Fe (II)	ferrous iron
Fe (III)	ferric iron
FFS	focused feasibility study
FS	feasibility study
ft/yr	feet per year
GC/MS	gas chromatography/mass spectroscopy
GEOD	GEOD Corporation
gpm	gallons per minute
g/cm ³	grams per cubic centimeter
GWSI	ground-water site inventory
Hex Cr	hexavalent chromium
hr ⁻¹	per hour
ICP	inductively coupled plasma
IDW	investigation-derived waste
IGWSCC	Impact to Groundwater Soil Cleanup Criteria
K	hydraulic conductivity
K _d	soil/water partition coefficient
l/kg	liter per kilogram
MCAWW	Methods for Chemical Analysis of Water and Wastes
MCL	maximum contaminant level
MGAW	Methods and Guidance for Analysis of Water

LIST OF ACRONYMS (Continued)

Mercon	Mercon Industries
µg/L	micrograms per liter
µm	micron
MGD	million gallons per day
mg/kg	milligram per kilogram
mg/L	milligrams per liter
MIBK	4-methyl-2-pentanone
MRDL	method required detection limit
MRL	minimum reporting levels
MTBE	methyl-tertiary butyl ether
NAD	North American Datum
NGVD	National Geodetic Vertical Datum
NJDEP	New Jersey Department of Environmental Protection
NRDCSCC	Non- Residential Direct Contact Soil Cleanup Criteria
NPL	National Priorities List
NWIS	National Water Information System
OD	outside diameter
ORP	oxidation-reduction potential
OU	operable unit
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
ppb/v	parts per billion by volume
PRM	Potomac-Raritan-Magothy
Puchack Site	Puchack Well Field Superfund Site
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
R	retardation factor
RA	risk assessment
RAC II	Response Action Contract
RI	remedial investigation
RI/FS	remedial investigation/feasibility study
RPD	relative percent difference
RPM	Remedial Project Manager
SC	specific conductivity
SGL Chrome	SGL Modern Hard Chrome Service
SM	standard methods
SMEWW	Standard Methods for Examination of Water and Wastes
SOP	standard operating procedure
SP	spontaneous potential
SPR	single-point resistance
SSL-1DAF	Soil Screening Level, migration to groundwater, Dilution Attenuation Factor of 1
STL	Severn Trent Laboratories, Inc.
Supertire	Supertire Services, Incorporated

LIST OF ACRONYMS (Continued)

SVOC	semi-volatile organic compounds
SW846	18 th Edition and Test Methods for Evaluating Solid Waste, Physical/Chemical Methods
TAL	target analyte list
1,1,1-TCA	1,1,1-trichloroethane
TCE	trichloroethene
TCL	target compound list
TOC	total organic carbon
Total Cr	total chromium
USGS	United States Geological Survey
VOC	volatile organic compound

EXECUTIVE SUMMARY

PURPOSE OF THE REPORT

CDM Federal Programs Corporation (CDM) is conducting a Remedial Investigation/Feasibility Study (RI/FS) for Operable Unit (OU) 1 of the Puchack Well Field Superfund Site (the Puchack Site) for the United States Environmental Protection Agency (EPA), Region II, as authorized under the RAC II Contract 68-W-98-210, Work Assignment Number 102-RICO-02JL. The United States Geological Survey (USGS), through an inter-agency agreement with EPA, directed the planning and execution of the field investigation. EPA's Environmental Response Team (ERT) also assisted in the planning and collection of stratigraphic sediment samples from the potential source areas. This report presents the results of the Remedial Investigation (RI) of OU1. This report has been prepared by CDM, with significant input from the USGS.

Because of the nature and complexity of the contamination at the Puchack Site, EPA is handling the investigation and cleanup of the Puchack Site in two operable units. OU1, which is also referred to as Phase I, involves the investigation and cleanup of site-wide chromium contaminated groundwater, as well as associated volatile and semivolatile organic compounds (VOCs and SVOCs) present in conjunction with the chromium. OU2, which will be the next phase, deals with the investigation and cleanup of source areas that contributed chromium and associated VOCs and SVOCs to the groundwater contamination.

To provide a comprehensive understanding of the Puchack Site settings and contamination, the RI covers an area which encompasses the Puchack Site as well as adjacent areas that are not considered part of the Puchack Site. The RI report includes the RI results for these adjacent areas even though they are not contributing to the Puchack Site contamination.

SITE DESCRIPTION

The Puchack Well Field Superfund Site is located in a commercial, industrial, and residential neighborhood of Pennsauken Township, Camden County, New Jersey. The Puchack Site for OU1 is defined by the location of the chromium contamination in groundwater, which is defined by the 100 micrograms per liter ($\mu\text{g/L}$) chromium isoconcentration line. The 100 $\mu\text{g/L}$ chromium isoconcentration line was chosen because this is the EPA's and the New Jersey Department of Environmental Protection's (NJDEP) Maximum Contaminant Level (MCL) for chromium. Groundwater sampling data obtained from 1999 to 2001 were used to draw a 100 $\mu\text{g/L}$ isoconcentration line, which shows that the chromium contaminated groundwater is situated in an area roughly bounded to the north by Route 90, to the east by Westfield Avenue, to the south by Cove Road, and to the west by the Conrail railroad track. Residences, schools, churches, commercial buildings, industrial development, and two cemeteries occupy this area.

The Puchack well field is located within OU1 and consists of six municipal supply wells that are owned and were operated by the City of Camden. During operation, the six wells had a combined capacity of six million gallons per day (mgd). The area surrounding the well field is used for residential, commercial, and industrial purposes. Several hundred single and multi-family residential buildings, commercial buildings, and industrial facilities are located near the Puchack well field. One section of the Pennsauken Industrial Park is located approximately one-half mile to

the northeast of the Puchack well field, while another section of the industrial park is located approximately one-quarter mile to the southwest. Conrail railroad tracks are situated approximately 500 feet to the northeast and southeast of the well field and the tollgate for the Betsy Ross Bridge (Route 90) is located approximately 250 feet to the east.

SITE HISTORY

Groundwater contamination, consisting of trichloroethene (TCE), 1,2-dichloroethane (1,2-DCA), tetrachlorethene (PCE), and chromium, was first detected at Puchack 4R/6-70 in the early 1970s. Further sampling indicated the presence of hexavalent chromium (relatively high solubility and toxicity) and trivalent chromium (relatively low solubility and toxicity) at concentrations above the EPA MCL (100 µg/L). In 1978, chromium was detected in Puchack 5/5A. In 1982, chromium was detected in Puchack 2, 3/3A, and 6-75/7. Historical chromium concentrations ranged from 1500 to 3000 µg/L. In 1984, general use of the well field was terminated. However, control pumping of Puchack 1 was instituted to act as tentative plume containment measure. The pumping was terminated in 1998 due to concerns about the requirements of treating water withdrawn from the well.

In 1986, CDM investigated the chromium contamination in the well field on behalf of the NJDEP. CDM found chromium concentrations up to 1000 µg/L, mercury concentrations up to 5.8 µg/L, and TCE concentrations up to 70 µg/L in the well field.

In 1992, CDM was tasked by NJDEP to conduct a pilot scale treatability study of the contaminated groundwater at Puchack well field, which had an average hexavalent chromium concentration of 2,500 µg/L. Over a two month period, 1.7 million gallons of groundwater was treated. The pilot scale system demonstrated that chromium levels in treated water below 50 µg/L could be consistently achieved, and levels below 20 µg/L were reached for most of the pilot test conditions using ferrous iron as the reducing agent. The nearby Morris well field water, which contained 30 to 45 milligrams per liter (mg/L) of iron, was considered as a potential source of ferrous iron.

In March of 1996, NJDEP collected samples from the Puchack supply wells and monitoring wells. Analytical results indicated chromium, mercury, and TCE in all of the supply wells.

Several contaminated sites were identified as potential chromium source areas for the Puchack well field by NJDEP in Pennsauken Township in the early 1980s. Potentially contaminated sites located within or near the Puchack well field Site include SGL Modern Hard Chrome Service (SGL Chrome), King Arthur, Mercon, and Supertire, among others. The SGL Chrome site was used for chromium plating and is currently a parking lot with no historical structural features remaining.

In 1997, the USGS, in cooperation with the NJDEP, initiated a field investigation of the groundwater contamination of the Pennsauken Township area. Groundwater contaminated with chromium was found in the Middle aquifer in two isolated areas, one located at the SGL Chrome property and one located to the north near the Pennsauken Landfill. (Groundwater contamination at the Pennsauken Landfill is not related to the Puchack Site.) The SGL site is also the location of the highest hexavalent chromium groundwater contamination in the Middle aquifer at 11,540 µg/L. Based on sampling results from the 1997-98 USGS investigation, total chromium levels in the Middle aquifer,

Intermediate Sand, and Lower aquifer generally ranged from non-detect to 10,250 µg/L, from 2 to 9,070 µg/L, and from non-detect to 3,454 µg/L, respectively.

The findings of the 1997-1998 sampling indicated that VOC contamination was more widespread, with multiple sources, and was present in pockets near contaminant source areas. VOC contamination in the three aquifers has commingled with the chromium plume and is generally larger in size. TCE, with estimated concentrations up to 140 µg/L, was the most frequently detected VOC. Other frequently detected VOCs included 1,1,1-trichloroethane (1,1,1-TCA) with estimated concentrations up to 12,500 µg/L, 1,1-dichloroethene (1,1-DCE) with estimated concentrations up to 3,580 µg/L, PCE with estimated concentrations up to 280 µg/L, and benzene with estimated concentrations up to 1,200 µg/L.

The Puchack Well Field Site was placed on the National Priorities List (NPL) on March 6, 1998.

STUDY AREA INVESTIGATION

The nature and distribution of groundwater contamination at and near the Puchack Well Field Site is complex. The results of previous investigations, including those conducted by the USGS in cooperation with the NJDEP, have identified numerous complexities of the aquifer system stratigraphy, hydrogeology, and geochemistry at the Puchack Site, as well as the existence of multiple potential contaminant sources and changes in historical pumping.

The USGS directed the field investigation at the Puchack Well Field Site to acquire data for the OU1 RI. The OU1 field investigation included the completion of soil borings, subsurface soil and aquifer sediment sampling, downhole geophysical surveys, monitoring well installation and development, groundwater sampling, and synoptic and continuous water level measurements. This work was conducted from July 20, 2000 through June 8, 2001.

The USGS was responsible for the planning and protocols required for the OU1 RI field activities. All locations, procedures, and protocols for the installation of the monitoring wells were provided by the USGS. CDM provided technical support and subcontracted services for drilling, well installation, surveying, waste management, and chemical analyses.

The following activities were completed:

- A total of 16 borings were advanced using hollow stem auger methods at selected potential source areas. A total of 60 soil and geologic sediment samples were collected for chemical analyses.
- A total of 28 borings were advanced using mud rotary drilling methods.
- A total of 47 subsurface soil and geologic sediment samples (and 6 duplicate samples) were collected from 43 monitoring well borings for chemical analysis.
- Downhole geophysical logging was conducted by the USGS at 27 locations.
- A total of 64 monitoring wells were installed and developed at 27 clusters during the RI field investigation.
- Thirteen groundwater samples from 13 monitoring and water supply wells were collected for chemical analyses from October 1999 to December 1999.

- 135 groundwater samples from 88 monitoring wells were collected for chemical analyses from August 2000 to April 2001.

Groundwater quality in the Potomac-Raritan-Magothy aquifer system in Pennsauken Township has been affected by both inorganic and organic contaminants. Stratigraphic and hydrologic data gathered at newly installed monitoring wells has led to refined interpretations of local hydrostratigraphy, groundwater flow directions, and hydraulic gradients. Thus, the distribution of contaminants in the aquifer system can be better understood in light of these interpretations. Results of the present investigation include the following significant findings.

HYDROGEOLOGY

- There are four water-bearing units: the Upper aquifer (mostly unsaturated in the study area), the Middle aquifer, the Intermediate Sand, and the Lower aquifer, all separated by leaky confining units.
- A detailed delineation of the hydrostratigraphic framework in the study area indicates that there are areas of cut-and-fill in the confining units. These create permeable zones that apparently do not prevent passage of water through the confining units.
- There are downward head gradients between the Middle aquifer and Intermediate Sand that promote movement of contaminated water between these two water-bearing units.
- Although hydraulic heads between the Intermediate Sand and the Lower aquifer are now similar, it is likely that during full-scale pumping at the Puchack well field, a greater downward head gradient between these two units existed. These conditions probably contributed to the movement of chromium contamination out of the Intermediate Sand into the Lower aquifer and to the Puchack wells.
- During full-scale pumping at the Puchack well field, groundwater flow directions, locally, were probably toward the northeast, but now have shifted to the southeast.
- A general increase in water level elevations of over 2 feet in all aquifers from 1998 to 2000 was observed.

NATURE AND EXTENT OF CONTAMINATION

Inorganic Contamination in Groundwater

Hexavalent chromium contamination is the primary concern at the Puchack Site. There also are scattered detections of mercury with no apparent pattern. Major findings of chromium contamination include:

- Chromium-contaminated groundwater forms plumes in each of three water-bearing zones: the Middle aquifer, the Intermediate Sand, and the Lower aquifer.
- Chromium-contaminated groundwater has moved through breaches in confining units between the water-bearing zones in response to downward vertical head gradients, resulting in contamination reaching deeper water bearing units.
- The plumes in the Intermediate Sand and Lower aquifer are moving to the southeast, an apparent shift in direction since shut down of the Puchack well field.

- Chromium concentrations in the groundwater plumes have decreased from 1997-1998 to 2000-2001.
- It is not clear whether the decreases in chromium concentrations are the result of reduction of hexavalent chromium and precipitation of the resulting trivalent chromium, whether hexavalent chromium is adsorbing to aquifer materials, or whether physical movement (advection and dispersion) of the plumes has led to decreases in concentration at a given well. Based on existing data, it is likely that all three processes have affected chromium concentrations.

Organic Contamination in Groundwater

- The most frequently detected volatile organic contaminant is TCE; others, including PCE; 1,1,1-TCA; and BTEX, are detected less frequently.
- VOC contamination is more widespread in all water-bearing units than chromium contamination. Coherent VOC plumes have not been identified.
- Based on the variety of compounds and widespread distribution, multiple sources of VOCs are likely.
- At several locations VOC concentrations have declined and there is evidence of degradation of the VOCs, particularly the chlorinated compounds, as cis-1,2-dichloroethene and vinyl chloride are detected, and their frequency and concentrations increase with depth in the aquifer system.
- As with the chromium plume, there is evidence of movement of VOC contamination.

While VOCs were encountered within the boundaries of the Puchack Site chromium plume, coherent VOC plumes have not been identified. Within the vicinity of the Puchack Site the VOC hot spots that were encountered during the OU1 RI have commingled with the chromium plume. VOC hot spots outside of the Puchack chromium plume are not included in the scope of the Puchack Site OU1 RI. The VOCs appear to have been released from several source areas. A hot spot is a well where a VOC exceeded its MCL in a water sample.

VOC contamination is a secondary concern at the Puchack Site. Remediation of associated, commingled VOC contamination is a secondary goal for remediation. EPA intends to include treatment of VOCs that are encountered during Puchack chromium plume capture. VOC contamination that is not captured within the chromium plume will be considered separately from the Puchack remediation.

Potential Contamination Sources

Limited investigations were conducted at five potential source areas. The major findings include:

- SGL Chrome property appears to be a source of chromium contamination, based on the high concentrations of chromium detected in soil and groundwater samples.
- Only sporadic chromium contamination, mostly at levels below background concentrations, was detected in samples from the four other properties investigated.
- Organic contamination was found in all five properties. The major contaminants included TCE, 1,1,1-TCA, and PCE.

- High concentrations of 1,1,1-TCA were detected in soil gas and soil samples from the Supertire property.

CONCLUSIONS

On the basis of data from this and previous investigations in the study area, the following conclusions can be drawn.

- Chromium-contaminated groundwater forms plumes in the Middle aquifer, Intermediate Sand, and Lower aquifer.
- Chromium concentrations are decreasing over time at most of the plume areas.
- Residual chromium contamination exists in soils and sediments overlying the Middle aquifer. This contamination may represent a continuing source of chromium to the aquifer system.
- The SGL Chrome property appears to be a source of chromium contamination for the Puchack well field, based on the high concentrations of chromium detected in soil and groundwater samples.
- Chromium and VOC contamination are commingled within the areas of the chromium plumes and VOC sources may or may not be associated with the sources of the chromium.
- The detailed delineation of the hydrostratigraphic framework has confirmed there are permeable parts of the confining units that are the result of a complex depositional and erosional geologic history. As a result, both inorganic and organic contaminants are able to migrate downward at certain locations.
- Groundwater flow directions have shifted from northeast to southeast, resulting from shut down of the Puchack well field.

RECOMMENDATIONS

The following data gaps have been identified and should be considered in planning future work:

- Although a likely source of chromium contamination in the Middle aquifer has been identified, the current extent of chromium contamination in the Middle aquifer has not been conclusively determined. Consequently, all the potential sources of the chromium contamination that has reached the Intermediate Sand and the Lower aquifer may not have been identified.
- The extent of the VOC contamination in the study area soils and sediments has not been fully investigated, although some potential sources have been identified.

EPA plans to conduct OU2 investigations for the chromium source areas, which will provide answers to the data gaps identified above. EPA also plans to conduct treatability studies to formulate a cost effective remedy for the chromium plume.

1.0 INTRODUCTION

1.1 PURPOSE OF THE REPORT

CDM Federal Programs Corporation (CDM) is conducting a Remedial Investigation/Feasibility Study (RI/FS) of the Puchack Well Field Superfund Site (the Puchack Site) for the United States Environmental Protection Agency (EPA), Region II, as authorized under the Response Action Contract (RAC) II contract 68-W-98-210, Work Assignment number 102-RICO-02JL. This report presents the methodologies and results of the Remedial Investigation (RI) of Operable Unit (OU) 1. This report has been prepared by CDM, with significant input from the United States Geological Survey (USGS).

Due to the complexity of the Puchack Site, EPA divided the Puchack Site into two OUs. OU1 involves the investigation and cleanup of site-wide chromium contaminated groundwater, as well as associated volatile and semi-volatile organic compounds (VOCs and SVOCs) present in conjunction with the chromium. OU2 will address the investigation and cleanup of source areas that contributed chromium and associated VOCs and SVOCs to the groundwater contamination.

The main objectives of the OU1 RI are:

1. Characterize the nature and extent of the groundwater plume contaminated with chromium and associated metals, volatile and semi-volatile organic contamination;
2. Design and conduct of a hydrogeologic investigation to complement an existing monitoring well network to fill data gaps in the hydrostratigraphic framework to support the development of a site specific groundwater computer model and understand the fate and transport of contaminants;
3. Summarize and evaluate the usability of data collected during previous investigations;
4. Identify State and Federal applicable or relevant and appropriate requirements (ARARs);
5. Perform a baseline risk assessment, and;
6. Develop remedial objectives for a groundwater remedy.

Based on the results of the RI, remedial objectives and a full range of alternatives will be developed and evaluated in the OU1 Feasibility Study Report (FS).

Several agencies were involved in the planning and execution of this RI: EPA is the lead agency; USGS, through an inter-agency agreement, directed the planning and execution of the field activities; and EPA's Environmental Response Team (ERT) assisted in the planning and collection of stratigraphic sediment samples. From July 2000 to June 2001, CDM, with participation from the USGS and the ERT, completed the following field activities:

1. Soil and sediment sampling at potential source areas
2. Soil and stratigraphic sediment sampling during monitoring well borehole drilling
3. Geophysical borehole logging
4. Installation of 64 monitoring wells
5. Groundwater sampling (24 existing monitoring wells and 64 newly installed wells)

6. Water level measurements
7. Well surveying

RI field work was conducted in accordance with the Final Work Plan Volume I, dated May 18, 2000 (CDM 2000a) and the Final Quality Assurance Project Plan (QAPP) dated June 2, 2000 (CDM 2000b).

To provide a comprehensive understanding of the Puchack Site, the RI covers an area which encompasses the Puchack Site as well as adjacent areas that are not considered part of the Puchack Site. The RI report includes the results for these adjacent areas even though they are not part of the Puchack Site.

1.2 SITE DESCRIPTION

Puchack Well Field Superfund Site

The Puchack Well Field Superfund Site (the Puchack Site) is located in a commercial/industrial and residential neighborhood of Pennsauken Township, Camden County, New Jersey (Figure 1-1). OU1 at the Puchack Site is defined by the location of the chromium contamination in groundwater, which is defined by the 100 micrograms per liter ($\mu\text{g/L}$) chromium isoconcentration line. The 100 $\mu\text{g/L}$ chromium isoconcentration line was chosen because this is the EPA and the New Jersey Department of Environmental Protection (NJDEP) Maximum Contaminant Level (MCL) for chromium. Groundwater sampling data obtained in 1999-2001 were used to draw a 100 $\mu\text{g/L}$ isoconcentration line, which shows that the chromium contaminated groundwater is situated in an area roughly bounded to the north by Route 90, to the east by Westfield Avenue, to the south by Cove Road, and to the west by the Conrail railroad track (Figure 1-2).

The area within and surrounding the site is used for residential, commercial, and industrial purposes. Several hundred single and multi-family residential buildings, commercial buildings, and industrial facilities are located within a two-mile radius of the Puchack Site. One section of the Pennsauken Industrial Park is located approximately one-half mile to the northeast of the Puchack site while another section of the industrial park is located approximately several hundred feet to the southwest. A Conrail railroad track runs through the site and the tollgate for the Betsy Ross Bridge (Route 90) is located east of the site.

Puchack Well Field

The Puchack well field, which is located within the OU1 boundary of the Puchack Site, consists of six municipal supply wells that are owned and were operated by the City of Camden. The six public supply wells are referred to as Puchack 1, 2, 3 (also referred to as 3A), 5 (also referred to as 5A), 4R/6-70, and 6-75/7. All six wells are located within the area bounded by Route 90 (Betsy Ross Bridge) to the northeast, Forrest Avenue to the southeast, Derousse Avenue to the southwest, and River Road to the northwest. Three of the wells are located in the vicinity of Sculley Park. The other three wells are located within residential areas. Figure 1-2 shows the location of the well field. According to construction logs, the well depths range from 141 feet (Puchack1) to 220 feet (Puchack 4R/6-70) below ground surface. During operation, the six wells had a combined capacity of six million gallons per day (mgd). A seventh Puchack supply well, No. 4/SEALED, was reportedly

destroyed during the construction of the adjacent Betsy Ross Bridge that spans the Delaware River and connects New Jersey and Pennsylvania.

1.3 SITE HISTORY

Groundwater contamination, consisting of trichloroethene (TCE), 1,2-dichloroethane (1,2-DCA), tetrachlorethene (PCE), and chromium, was first detected at Puchack 4R/6-70 in the early 1970s. Further sampling indicated the presence of hexavalent chromium (relatively high solubility and toxicity) and trivalent chromium (relatively low solubility and toxicity) at concentrations above the EPA MCL, which resulted in Puchack 4R/6-70 being removed from service in 1975. This was a significant loss to the supply system since Puchack 6 was one of the city's most productive wells, with a capacity of up to 3.2 mgd. In 1978, chromium was detected in Puchack 5/5A. This well was removed from service sometime between 1981 and 1983. In 1982, chromium was detected in Puchack 2, 3/3A, and 6-75/7. Historical chromium concentrations ranged from 1500 to 3000 µg/L (Weston 1997). In 1984, general use of the well field was terminated. However, NJDEP allowed the continued controlled pumping of Puchack 1 to act as a temporary plume containment measure. Groundwater extracted from Puchack 1 was either discharged to Puchack Creek next to the Puchack Site or blended with the Camden City potable water supply. The pumping was discontinued on April 20, 1998 due to concerns about the requirements for treating water withdrawn from Puchack Puchack 1.

In 1986, CDM investigated the chromium contamination in the well field on behalf of the State of New Jersey. The CDM investigation documented chromium concentrations up to 1000 µg/L, mercury concentrations up to 5.8 µg/L, and TCE concentrations up to 70 µg/L in the well field (CDM 1986).

In October of 1991, the NJDEP issued a Directive and Notice to Insurers to a number of facilities or companies in the Puchack Site vicinity that it "believed...to be responsible for the discharge of... hazardous substances" that subsequently contaminated the groundwater. NJDEP determined what facilities would receive the directives "based upon a review of the hydrogeologic conditions that exist at the well field" and existing documentation of facility operations and discharges (Weston 1997). Among the 22 facilities or companies identified are Advance Process Supply Company (APS); Davidson-Pacific Wood Products; King Arthur, Incorporated; Mercon Industries (Mercon); SL Modern Hard Chrome (formerly SGL Modern Hard Chrome Service) (SGL Chrome); and Supertire Services, Incorporated (Supertire); all are suspected source areas for the Puchack Well Field Site. NJDEP, as well as the potentially responsible parties for some of the properties, have conducted investigations of the six properties. To date, the specific source or sources of the contaminants detected in the Puchack wells may not have all been identified.

In 1992, CDM was tasked by NJDEP to conduct a pilot scale treatability study of the contaminated groundwater at Puchack well field, which had an average hexavalent chromium concentration of 2,500 µg/L. Over a two month period, 1.7 million gallons of groundwater was treated. The pilot scale system demonstrated that chromium levels in treated water below 50 µg/L could be consistently achieved, and levels below 20 µg/L were reached for most of the pilot test conditions using ferrous iron as the reducing agent. The nearby Morris well field water, which contained 30 to 45 milligram per liter (mg/L) of iron, was considered as a potential source of ferrous iron.

In March of 1996, NJDEP collected samples from the Puchack supply wells and monitoring wells. The samples were analyzed for VOCs, total metals, and cyanide. Analytical results indicated chromium, mercury, and TCE in all of the supply wells. Detected chromium concentrations ranged from 46.6 µg/L in Puchack 1 to 1,410 µg/L in Puchack 6-75/7. Mercury concentrations ranged from 0.15 µg/L in Puchack 4R/6-70 to 0.77 µg/L in Puchack 2. TCE concentrations ranged from 0.3 µg/L in Puchack 5/5AA to 20 µg/L in Puchack 2 (Weston 1997).

In 1997, USGS, in cooperation with the NJDEP, initiated a field investigation to organize existing groundwater quality data, groundwater usage, groundwater levels, and hydrogeology of the Pennsauken Township area. As part of this investigation, a drilling and sampling program was conducted to obtain additional information on the extent of groundwater contamination related to the Puchack Site and to enhance the understanding of the area's hydrogeologic conditions. This investigation included the following tasks:

- Twenty-six wells, in 12 clusters, were installed and subsequently sampled.
- Geophysical logs were run in each of the 12 well cluster locations.
- Twenty-nine additional existing wells were sampled.
- Water level measurements were collected from 128 monitoring and water supply wells located at facilities throughout the study area to better define hydraulic gradients and groundwater flow directions in the Lower and Middle PRM aquifer.
- USGS initiated the development of a groundwater flow model for the Pennsauken Township area.

The draft USGS report (Walker and Jacobsen in press) summarizes the results of the 1997-1998 USGS/NJDEP field investigation. Groundwater contaminated with chromium was found in the Middle aquifer in two isolated areas: one located at the SGL Chrome property and one located near the Pennsauken Landfill north of the Puchack Site. (Groundwater contamination at the Pennsauken Landfill is not related to the Puchack Site.) The SGL site is also the location of the highest hexavalent chromium groundwater contamination in the Middle aquifer at 11,540 µg/L. Based on sampling results from the 1997-1998 USGS investigation, total chromium levels in the Middle aquifer, Intermediate Sand, and Lower aquifer generally ranged from non-detect to 10,250 µg/L, 2 to 9,070 µg/L, and from non-detect to 3,454 µg/L, respectively.

The findings of the 1997-1998 USGS sampling indicated that VOC contamination was more widespread, with multiple sources, and was present in pockets near contaminant source areas. VOC contamination in the three aquifers has commingled with the chromium plume and is generally larger in size. TCE, with estimated concentrations up to 140 µg/L, was the most frequently detected VOC. Other frequently detected VOCs included 1,1,1-trichloroethane (1,1,1-TCA) with estimated concentrations up to 12,500 µg/L, 1,1-dichloroethene (1,1-DCE) with estimated concentrations up to 3,580 µg/L, PCE with estimated concentrations up to 280 µg/L, and benzene with estimated concentrations up to 1,200 µg/L. Portions of the investigation results are discussed and compared to the current RI results in Section 4 of this report with proper reference noted.

The site was proposed for inclusion on the National Priorities List (NPL) in September of 1997 and was placed on the NPL on March 6, 1998.

1.4 REPORT ORGANIZATION

This RI report is organized in the following manner with tables and figures presented following each section. A baseline human health risk assessment (RA) was prepared and submitted to EPA separately. It will be incorporated into the final version of this document. A cultural resources survey has not been performed as part of the current scope of work.

Section 1	INTRODUCTION, presents an overview of the Puchack Well Field Superfund Site and summarizes the Puchack Site history and previous site investigations.
Section 2	STUDY AREA INVESTIGATIONS, describes the areas of concern and describes the methodology and sampling rationale for the various investigations conducted for the Phase I RI.
Section 3	PHYSICAL CHARACTERISTICS OF THE STUDY AREA, describes the physical attributes of the study area, including surface topography, meteorology, surface water hydrology, geology, and hydrogeology. Sections on demography and land use describe the area's potential human receptors.
Section 4	NATURE AND EXTENT OF CONTAMINATION, lists the groundwater action levels against which site data were screened to determine the extent of contamination, discusses the quality and usability of analytical data obtained during the investigation, and describes the type and extent of contamination.
Section 5	CONTAMINANT FATE AND TRANSPORT, evaluates the persistence and mobility in the environment of the various types of contamination identified, and summarizes the fate and transport mechanisms that apply to the Puchack Site.
Section 6	BASELINE HUMAN HEALTH RISK ASSESSMENT, evaluates the risk calculations for human exposure scenarios. This section has been omitted from this draft document. It has been submitted under separate cover.
Section 7	SUMMARY AND CONCLUSIONS, summarizes the significant determinations of the remedial investigation.
Section 8	REFERENCES.

2.0 STUDY AREA INVESTIGATIONS

CDM, in cooperation with the USGS, conducted a field investigation at the Puchack Site to acquire data for the OU1 RI. The field investigation was conducted in accordance with the following EPA- and NJDEP-approved project plans:

- The CDM Final RI/FS Work Plan Volume I (CDM 2000a)
- The CDM Final RI/FS QAPP (CDM 2000b)
- The CDM Addendum to the Final RI/FS QAPP (CDM 2000c)
- The USGS Final QAPP for the Field Data Collection (USGS 2000)

The OU1 RI field investigation included the completion of soil borings, subsurface sediment sampling, downhole geophysical surveys, monitoring well installation and development, groundwater sampling, and synoptic and continuous water level monitoring. This work was conducted from July 20, 2000 through June 8, 2001, except the continuous water level monitoring which began in February 2000. The results of the groundwater sampling conducted by the USGS during the period of October 1999 through December 1999 are included in this report. Table 2-1 summarizes the field activities conducted during the OU1 RI.

The deviations from the CDM QAPP, made during the field investigation, were documented on Field Change Request (FCR) Forms included in Appendix A. Each Field Change Request Form describes the deviation to the QAPP, the reason for the deviation, and the recommended modification. The deviation was agreed upon by the CDM Site Manager and the USGS Project Manager and then the EPA Remedial Project Manager (RPM) was notified of the reason for the change. The changes were made in response to conditions encountered in the field, and to add to the overall representativeness, completeness, precision, or accuracy of the data collected in the field. Following is a list of the field change requests:

- FCR 1: changed ERT soil boring sample collection procedures
- FCR 2: specified additional split spoon sampling at monitoring well MW-12
- FCR 3: added groundwater sample collection from ERT soil borings
- FCR 4: addressed need to case some ERT soil borings
- FCR 5: collect groundwater samples for VOC analysis while drilling the ERT soil borings at the Supertire property
- FCR 6: changed plan for collection of 3-inch split-spoons at monitoring well pilot borings
- FCR 7: modified the boring depth at the King Arthur property
- FCR 8: dropped 2-inch split spoon sampling at CCWD MW-4I
- FCR 9: dropped TCL VOC analysis for soil sample field blanks because EnCore® samplers were used
- FCR 10: changed sampling plan at CCWD MW-2D
- FCR 11: changed sampling plan at CCWD MW-6I
- FCR 12: changed sampling plan at CCWD MW-1D

2.1 CONTAMINANT SOURCE INVESTIGATIONS

CDM, in cooperation with EPA's ERT, conducted a contaminant source investigation concurrent with the OU1, Phase I RI field investigation. The results of this investigation are discussed in the Analytical Summary of EPA ERT Soil Boring Report (CDM 2001b). The results of this sampling program, as they relate to groundwater contamination, are discussed in detail in this RI report.

2.2 METEOROLOGICAL INVESTIGATIONS

CDM obtained monthly and yearly data on average temperature and precipitation for the Pennsauken area (Philadelphia monitoring station) from the Pennsylvania State Climatologist at Penn State University. The meteorological data collected by CDM are discussed in Section 3.2 of this report.

2.3 GEOLOGICAL AND HYDROGEOLOGICAL INVESTIGATIONS

2.3.1 OVERVIEW

The USGS, with technical assistance from CDM, performed a geological and hydrogeological investigation as part of the OU1 RI for the Puchack Site. This investigation also gathered data to define the nature and extent of groundwater contamination at the Puchack Site and support the ongoing groundwater flow models being created by the USGS for both the Puchack site and the regional Pennsauken Township area, which began in 1997. As a result, the USGS assisted with the planning and protocols for the OU1 monitoring well installations. In addition, all locations, procedures, and protocols for the installation of the monitoring wells were provided by the USGS. CDM prepared a work plan and QAPP for the EPA, and procured and managed drilling, surveying, waste management, and laboratory subcontractors. Monitoring wells were drilled, installed, and developed by CDM's drilling subcontractor, Uni-Tech Drilling Corporation (Uni-Tech).

The nature and extent of contamination in and near the Puchack site is complex. There are numerous complexities within the aquifer system stratigraphy, hydrogeology, and geochemistry, as well as multiple potential source areas of groundwater contamination. During 1996-1998, the NJDEP and USGS conducted an investigation to delineate the nature and extent of contamination. A monitoring well network was designed to provide detailed 3-dimensional information of the aquifer system; provide information on its hydraulic structure, geochemistry, and properties; identify confining layers; determine the nature and extent of chromium contamination, and identify potential pathways of contaminant transport. As part of this effort, 26 new monitoring wells were installed and 55 existing wells were sampled. However, the effort was not sufficient to gather the data necessary to complete the program objectives. Prior to the completion of the NJDEP effort, the site was listed on the NPL and EPA became the lead agency. In order to complement the existing well network and to fill data gaps, as part of the OU1 RI effort, EPA installed 64 additional monitoring wells. This increased the well network to a total of 242 wells that included the public water supply well fields that surround the Puchack Site, and extends into Burlington County.

Prior to the start of the field investigation, the general locations of the well clusters were selected by the USGS in consultation with the EPA. Based on this process, 58 monitoring wells were proposed for installation by the USGS. During the initial OU1 RI monitoring well installation program, the highest priority wells were installed by CDM and Uni-Tech. The priority was assigned

by the USGS and was based on data needs for groundwater model development and to provide information for deciding where to install additional monitoring wells. Using the sample analytical and hydrogeologic data from initial sampling as it became available, the USGS, in consultation with EPA, finalized the number, location, and depths of monitoring wells that were installed during the second round of drilling. During the field investigation, the USGS decided that additional monitoring wells were required and that some of the proposed wells were unnecessary. As a result, 11 monitoring well locations were added and five were deleted, for a total of 64 wells installed at 30 locations.

Table 2-2 lists all monitoring wells proposed and installed for the OU1 RI field investigation. The locations of all 64 CDM/USGS monitoring wells installed during the 2000-2001 OU1 RI are shown on Figure 2-1. Table 2-3 lists all the wells in the EPA/USGS monitoring network that have been used during this project and includes the 64 wells installed during the OU1 RI. Table 2-3 also includes wells where water level observations were made, groundwater samples were collected, lithologic data were obtained, and/or selected water supply wells located in or near the Puchack Site. The locations of the monitoring wells used for synoptic water-level measurements during the 2000-2001 OU1 RI are shown on Figure 2-2. The location of the 242 wells included in the EPA/USGS network are shown on Plate 1.

Specifically, the 64 monitoring wells installed during the OU1 RI were designed to:

- Provide geologic data needed to further refine the interpretation of the hydrostratigraphic framework
- Provide water quality data to define ambient conditions in the aquifer system in the study area
- Define the current extent of the plume(s) of chromium-contaminated groundwater to determine whether contamination had migrated since 1998
- Improve the assessment of the extent and nature of organic contaminants in groundwater underlying the study area
- Provide lithologic and chemical composition data of subsurface materials within the aquifer
- Supplement the data required for the USGS modeling efforts
- Support the data needs of both the baseline RA and the FFS

The investigation included six tasks, which are discussed in detail in the following subsections.

- Deep pilot borehole advancement
- Subsurface soil and aquifer sediment sampling
- Downhole geophysical logging
- Monitoring well installation and development
- Groundwater sampling
- Water level measurements

2.3.2 DEEP PILOT BOREHOLE ADVANCEMENT

At the deep monitoring well location at each well cluster, prior to well installation, a boring was advanced by Uni-Tech to collect subsurface sediment samples for lithologic characterization and for chemical analysis. As the boring was advanced, downhole geophysical logging was conducted before outer casing or well installation. Target depths for each deep boring were determined by the USGS prior to the start of the field investigation. The information gained from lithologic samples and downhole geophysical logging was used by the USGS to determine where to install the outer casing at the deep well and at the remaining, shallower wells in the cluster. In addition, the lithologic and geophysical data were used to finalize the screen interval depths for each well in the cluster. The outer casing was installed to help prevent the transport of contaminants from shallow zones to deeper zones. Borings were advanced according to specifications outlined in the CDM QAPP except that a 6-inch or 8-inch diameter pilot hole was advanced first, and then reamed with successively larger diameter drill bits, as needed, in order to maintain a straight borehole. A total of 28 borings were advanced using mud rotary drilling methods. The CDM field geologist logged drill cuttings and noted drilling comments from the driller, for inclusion in the boring logs. Significant clay layers, as defined by the USGS, were encountered in all but one (MW-21S) of the borings, necessitating the installation of outer steel casing. The USGS required the installation of a 12-inch and an 8-inch diameter outer steel casing at monitoring well MW-21D due to the presence of two significant clay layers.

Boring logs are presented in Appendix B. Subsurface soil and aquifer sediment samples were collected for lithologic characterization and chemical analysis, as discussed in Section 2.3.3 of this report. The USGS downhole geophysical logging procedures are discussed in Section 2.3.4 of this report. Several borings required partial backfilling prior to installation of the monitoring well. Monitoring well borehole backfilling procedures are discussed in Section 2.3.5.1 of this report.

2.3.3 SUBSURFACE SOIL AND AQUIFER SEDIMENT SAMPLING

Subsurface soil and aquifer sediment samples were collected during advancement of soil borings for lithologic characterization and chemical analyses.

2.3.3.1 Subsurface Soil and Aquifer Sediment Sampling for Lithologic Characterization

Subsurface soil and aquifer sediment samples were collected for lithologic characterization at 10-foot intervals from ground surface to the target depth of the borehole using two-inch outside diameter (OD) split spoons. Lithologic soil and aquifer sediment samples were collected according to specifications prepared by the USGS and detailed in the CDM QAPP. The following exceptions to the soil sample collection process were made by the USGS, in consultation with the EPA:

- Additional two-inch OD split spoon samples for lithologic characterization were collected in the soil boring at MW-12S in order to locate a clay layer.
- Two-inch OD split spoons for lithologic characterization were not collected in the boring at Camden City Water Department (CCWD) MW-4I due to the availability of lithologic information in nearby, existing monitoring wells.

- Two-inch OD split spoons for lithologic characterization were not collected in the first 100 feet at CCWD MW-2D due to the availability of lithologic information in nearby, existing monitoring wells.
- Two-inch OD split spoons for lithologic characterization could not be collected from intervals in some borings where a coarse gravel/cobble zone was encountered, resulting in poor sample retention.

2.3.3.2 Subsurface Soil Sampling for Chemical Analysis

A summary of subsurface soil and aquifer sediment samples collected during the field investigation is presented in Table 2-4. Results of soil sampling are discussed in Section 4.2 of this report. Quality assurance/quality control (QA/QC) samples collected in association with subsurface soil samples are discussed in Section 2.3.7.1 of this report.

A total of 47 subsurface soil samples (and 6 duplicate samples) were collected from 43 monitoring well borings for chemical analysis. Samples were sent to EPA's Contract Laboratory Program (CLP) organic and inorganic laboratories to be analyzed according to EPA methods for the following parameters: Target Compound List (TCL) VOCs, semi-volatile organic compounds (SVOCs), pesticides/polychlorinated biphenyls (PCBs), and Target Analyte List (TAL) metals and cyanide. Samples were sent to CDM's subcontract laboratory, Mitkem Corporation, for analysis of hexavalent chromium, according to EPA methods. In addition, seven samples were analyzed by CDM's subcontract laboratory for pH, total organic carbon (TOC), and grain size.

Subsurface soil samples for chemical analysis were collected using three-inch OD split spoons fitted with a laboratory-cleaned disposable acrylic liner. Soil and aquifer sediment samples were collected for chemical analysis according to specifications prepared by the USGS and outlined in the CDM QAPP, with the following exceptions made at the direction of the USGS in consultation with the EPA:

- Aquifer sediment samples for chemical analysis from the proposed screen zones of each monitoring well were collected from the deep boring advanced at each well cluster prior to well installation. However, this required that the soil sampling intervals be selected before the downhole geophysical log and lithologic information were available. Consequently, to ensure the sediment that was sent for chemical analyses were representative of the respective monitoring well screen zone, USGS, in consultation with the EPA, decided to collect samples from each screened zone in the respective monitoring well boring prior to well installation.
- Additional three-inch OD split spoons for chemical analysis were collected in the boring for CCWD MW-2D to obtain analytical data from screen intervals of two nearby, previously installed monitoring wells.
- Where a coarse gravel/cobble zone was encountered, samples for chemical analysis could not be obtained using the three-inch OD split spoons due to poor penetration and/or sample retention.
- Some samples collected for chemical analysis could not be analyzed for the full suite of analyses due to low sample volume. In such cases priority was given first to the analysis of total and hexavalent chromium, second to VOC analysis, and then all other parameters.

CDM labeled and stored on ice all subsurface soil and aquifer sediment samples as they were collected. CDM packed the samples on ice and sent them to EPA CLP laboratories and the subcontractor laboratory via FedEx priority overnight shipment. CDM completed sample chain-of-custody forms and necessary CLP paperwork which accompanied the samples to the laboratories.

2.3.3.3 Soil Sample Identifiers

ERT SOIL BORING SOIL SAMPLES

Soil samples collected during the ERT soil boring program conducted at Mercon, King Arthur, Supertire, and SGL were identified using the following syntax:

ERTSB99-X[-D]

where:

ERT	=	U.S. EPA Environmental Response Team Center
SB	=	soil boring
99	=	sequential location number, beginning with 01
-X	=	depth designator, “A” indicates the first sample, “B” the second sample and so forth from ground surface. A “Z” was used in the field to indicate a duplicate sample. (See discussion of duplicate sample designation below.)
[-D]	=	duplicate sample

For example the sample identifier “ERTSB06-B” indicates a soil sample collected from soil boring ERT-SB-06 from the second (B) depth interval down from ground surface.

ERT SOIL BORING WATER SAMPLES

During completion of the ERT soil borings, some groundwater or aqueous samples were collected using the hollow stem augers as a temporary piezometer.

If the depth designator is missing, this indicates the sample is an aqueous confirmatory sample analyzed for hexavalent chromium only:

Example: ERTSB06

If the letters “Q” or “R” are used as depth designators, this indicates that the sample is an aqueous screening sample which was analyzed for volatile organic compounds only.

Example: ERTSB09-Q

MONITORING WELL SOIL SAMPLES

Soil samples collected from monitoring well soil borings were identified using the following syntax:

MW99#SB-X[-D]

where:

MW	=	monitoring well location (for five samples this was preceded by “CCWD”)
99	=	sequential location number, beginning with 01
#	=	depth designator, six possible values:
D	=	deep
I	=	intermediate
M	=	shallow
S	=	shallow
WT	=	water table
EAST	=	east
SB	=	soil sample from the monitoring well boring
X	=	depth designator, A indicates the first sample, B the second sample and so forth from ground surface. A “Z” was used in the field to indicate a duplicate sample. (See discussion of duplicate sample designation below.)
[-D]	=	duplicate sample

For example the sample identifier “MW16DSB-A” indicates the first soil sample collected below ground surface from the boring for deep monitoring well MW-16D.

DUPLICATE SAMPLES

Field duplicate samples are designated in the database with the suffix “-D”.

In the field, the duplicate samples are given a depth designator of “-Z” to hide the sample location from the laboratory, thus making the sample a blind duplicate. The duplicate samples were renamed during data management when the “Z” depth designator was changed to the correct depth designator and “-D” suffix was appended to indicate a duplicate sample and to make both sample names unique.

Example: “MW14D-Z” used on the chain-of-custody is the same as “MW14D-B-D” in the data base

BLANKS

Field blank and water blank samples collected during the ERT soil boring and monitoring well boring programs were identified using the following syntax:

FBmmddyy-TT[-B]

where:

FB, WB	=	field blank, water blank
mm	=	2-digit month (January = 01)
dd	=	2-digit day of the month (the fifth = 05)
yy	=	last two digits of the year (2000 = 00, 2001 = 01)
TT	=	code to link the blank to the sampling event or other indicator, values for TT include:

SB	=	soil borings at the ERT sampling event
MW	=	monitoring well installations
DI	=	de-ionized water
TAP	=	tap water
-B	=	this suffix was used on some blanks to indicate additional analysis for volatile organic compounds only.

For example the sample identifier “FB101300-MW” indicates a field blank collected on October 13, 2000 (10/13/00) during the monitoring well soil sampling program.

2.3.4 DOWNHOLE GEOPHYSICAL LOGGING

Downhole geophysical logging was conducted by the USGS at 27 locations (Table 2-2 and Figure 2-1). Usually, the logs were run in the deep boring at each well cluster. Multiple geophysical log suite runs were completed as required during advancement of the borehole and construction of the monitoring well. Typically, the first geophysical log suite was run after the boring was completed to an initial depth and before an outer steel casing was installed. After the casing was installed and the borehole was advanced to its final depth but before the well was installed, the geophysical log suite was run again.

Because nearly all well construction required multiple casings, it was not possible to collect open hole logs for a given location in a single run. Logs were run in each open hole interval before casings were installed wherever possible to avoid signal attenuation caused by the presence of the casing. When boreholes were partially cased, gamma logs were run through the cased intervals to permit correlation with the logs run prior to casing installation in the same intervals. The open interval segments of the borehole logs were used by the USGS to gather lithologic data for use in determining the screened interval for each well and in correlating lithologic units between boreholes to refine the hydrostratigraphic framework.

The geophysical logs included natural gamma, borehole caliper, and a suite of electric logs including spontaneous potential (SP), single-point resistance (SPR), and normal resistivity logs of 8-, 16-, 32-, and 64-inch electrode spacing. The descriptions of the logs are:

- The *natural gamma log* provides a record of counts per second of naturally occurring gamma radiation, usually from the presence potassium-40. Because clay minerals tend to be rich in potassium, a gamma peak suggests the presence of clay minerals. However, sands rich in orthoclase feldspar will also give a high gamma count. Gamma logs can be run in cased or uncased wells, which contain liquid or are dry. However, casing attenuates the response, and must be considered in log interpretation.
- The *caliper log* provides a measurement of borehole diameter. Enlargements in the borehole diameter may indicate coarse sand and gravel zones that may have become unstable, causing the coarse sediments to be removed during the drilling process, whereas decreases of the borehole diameter may indicate areas of swelling clay. Variations in borehole diameter that affect the interpretations of other logs can be evaluated using the caliper log. Although the caliper log is only useful for these lithologic interpretations in the uncased portion of the borehole, it is useful in

determining the depth to which casing was installed or in determining other variations in casing construction. It is unaffected by the presence or absence of liquid.

- The *spontaneous-potential log* is a continuous measurement of naturally occurring potentials between the borehole fluid and the formation materials in and beyond in the borehole wall. The SP tool consists of a movable electrode that traverses the borehole on an insulated cable, a surface electrode ground and metering instrumentation that senses the changes in ohmic-potentials that occur between the electrode within the borehole and the fixed potential of the surface electrode due to the presence of more or less resistive lithologic beds. The SP log must be run in an uncased borehole containing a conductive fluid. The SP log is used chiefly for geologic correlation in combination with the single point resistance log described below.
- The *single-point resistance log* records the variations in electrical resistance in proportion to the changes in resistance of the borehole fluid and formation materials in and beyond the borehole wall. These changes, when expressed graphically, are interpreted to be due to changes in lithology. In general, increases in formation resistance results in a corresponding increase in the measured resistance. The SPR log must be run in an uncased fluid filled hole. The SPR log has a relatively small area of investigation and is therefore influenced by variations in resistance of borehole fluids and borehole diameter. The SP log described above and the SPR log together form an “electric log” of natural potentials and resistance. Together they were used in lithologic correlations and to determine bed thickness.
- The *normal resistivity log* measures the electrical resistivity of formation sediment adjacent to the borehole. The electrical resistivity of the sediment are related to the lithology and fluids present. Approximately 50 percent of the signal measured by the electrode comes from a volume whose radius is twice the electrode spacing. For example, the 16 inch normal tool has 50 percent of its signal coming from a 32 inch radius around the tool. The 64 inch normal tool has 50 percent of its signal coming from a 128 inch radius around the tool. The resolution of the normal devices are proportional to the electrode spacing.

Caliper, SP, SPR, and normal resistivity logs were run in open-hole intervals and, where casing was present, into the cased interval to confirm the position of the bottom of the casing. Gamma logs were run in each open-hole interval before casings were installed, wherever possible, to avoid the attenuation of the natural gamma radiation caused by the presence of the casing. When boreholes were partially cased, gamma logs were run through the cased intervals to permit correlation with logs run in the open-hole intervals prior to casing installation.

All geophysical logs were compared with lithologic sample descriptions and drilling characteristics to develop a comprehensive interpretation of the lithology at each borehole location. Significant changes in the signal response of each geophysical tool were evaluated graphically and interpreted as corresponding to changes in lithology; the response obtained with each tool provided additional information for the collective evaluation and interpretation of the logs. These interpretations provided the basis for selecting screen intervals during well construction, and later were used to correlate the significant stratigraphic layers encountered during drilling in order to refine the

interpretation of the hydrostratigraphic framework. Geophysical log suites collected at the new monitoring well locations are presented in Appendix C.

2.3.5 MONITORING WELL INSTALLATION AND DEVELOPMENT

A total of 64 monitoring wells were installed and developed at 30 clusters during the RI field investigation. The location of the 64 monitoring wells installed during the OU1 RI are shown on Figure 2-1.

The 64 monitoring wells installed during this investigation were named by the USGS “Puchack MW-xxx” or abbreviated to “P MW-xxx” in this report. CDM drilled some monitoring wells at existing monitoring well clusters. In such cases, the USGS choose a name for the new well that was consistent with the existing well names in the cluster. For example, wells drilled at existing Camden City Water Department (CCWD) well clusters had their names shortened from CCWD MW-YYY (or CC MW-YYY) to CC MW-YYY in the text and on the maps. Existing wells such as Camden City MW-1A were abbreviated to CC MW-1A.

Table 2-2 lists all monitoring wells installed for the OU1 RI field investigation. Monitoring well construction details are presented in Table 2-5. Monitoring well construction diagrams are located in Appendix D. Each monitoring well was installed in a specific aquifer zone. A suffix was added to the well name to designate the aquifer unit the well was completed in as follows:

M	Middle aquifer, e.g., MW-3M
I	Intermediate Sand, e.g., MW-13I
D	Lower aquifer, e.g., MW-13D
S	Shallow, e.g., MW-21S
WT	Water table, e.g., MW-12WT

However, in some cases the aquifer designation was revised after the well was completed. So, for example, a well designated MW-3M many actually be completed in the Intermediate Sand unit. The well names and aquifer units the screens are completed in are listed in Table 2-3.

2.3.5.1 Monitoring Well Borehole Backfilling

Several borings required backfilling prior to installation of the monitoring well. Backfilling was required due to either over-drilling to determine the depth to bedrock, or a change in screen interval to a shallower depth based on downhole geophysical and lithologic logs. Backfill intervals ranged from 20 feet to 115 feet. Backfill intervals, types, and rationale are summarized in Table 2-6.

Backfill materials varied, depending on the lithology of the intervals backfilled. Initially, all boreholes that required backfilling were backfilled with bentonite slurry and then sand. The slurry was allowed to settle for 24 hours prior to well installation. However, due to the physical instability of the bentonite slurry, this procedure was modified. Subsequent boreholes that did not include confining units within the backfill interval were backfilled with sand. Boreholes that included confining units in the backfill interval that needed to be sealed off were backfilled as follows:

1. No. 1 sand was placed up to the bottom of the confining unit.

2. Cement/bentonite grout was installed through the confining interval via tremie pipe.
3. The grout was allowed to sit for a minimum of 12 hours, after which time the top of the grout was measured to ensure that the confining interval was properly sealed.
4. A minimum of 5 feet of #00 sand was placed on top of the grout to act as a seal between the well screen and the grouted interval.
5. The monitoring well was then installed using typical installation procedures.

2.3.5.2 Monitoring Well Installation

While target well completion depths were agreed upon in advance by the USGS and EPA, final total depths, screen intervals, and outer casing depths for each monitoring well were finalized by the USGS in the field using lithologic and geophysical data. Multiple-casing well construction was used to prevent the transport of contaminants from shallow zones to deeper zones. Of the 64 wells installed, eleven were installed without an outer casing, 52 were cased with an outer 8-inch diameter steel casing, and one was double-cased with a 12-inch diameter steel outer casing and an 8-inch casing telescoped inside the 12-inch casing.

Monitoring wells were installed according to specifications outlined in the CDM QAPP, with the following exceptions:

- Well screens were either 5 or 10 feet in length, depending on the thickness of the unit to be screened.
- The bottoms of the well screens were either fitted with a bottom cap or a 5-foot tail piece with a bottom cap.
- Eight wells were finished with stick-up completions.

All well construction details were determined in the field by the USGS, in consultation with EPA, prior to installation. Finished wells were constructed of 4-inch flush-joint schedule 40 PVC casings and 5 or 10-foot long 0.010-inch slot-size screens. Conditions permitting, many of the wells were equipped with a 5-foot sump or tailpiece with bottom cap, attached to the bottom of the screen. All outer protective casings were constructed of welded black steel. Most wells were finished flush with land surface and secured with a water-tight lockable cap. Those wells finished above grade were protected with 8-inch steel casing with a lockable cap.

2.3.5.3 Monitoring Well Development

All monitoring wells installed during the RI field investigation were developed a minimum of 24 hours after installation. The purpose of well development was to remove drilling fluid, to improve the hydraulic connection between the well and the aquifer, to clear the well screen and tailpiece of solid material, and to set the sand pack around the well screen.

Two well development procedures were used at the Puchack Site:

- Air lift/swab method, which was used for wells greater than 100 feet deep
- Submersible pump method, which was used for wells less than 100 feet deep

Both methods used a combination of pumping and surging to achieve development of the wells. The air lift/swab method consisted of using a combination positive-pressure air line for pumping and a 4-inch diameter rubber swab tool for surging. The submersible pump method consisted of using a 4-inch diameter submersible pump as both the pump and surge tool. Surging was accomplished by manually lifting and lowering the pump within the screened zone. Well development procedures were as follows:

- Prior to installing development equipment, the total depth of the well and the water level depth were measured using a water level meter calibrated to 0.01 foot. The volume of water in both the well and the sand pack was calculated, assuming a sand pack porosity of 40 percent.
- The tail piece, if present, was pumped to remove any sediment that had settled to the bottom.
- The screen zone was developed in two-foot intervals by pumping at a rate of 5 - 20 gallons per minute (gpm) and surging.
- During development, measurements of pH, conductivity, turbidity, dissolved oxygen (DO), and temperature were recorded on in field log books.
- Development was considered complete when the water had cleared and the water quality measurements had stabilized.
- At the completion of development for each monitoring well, a sample of water was collected for field screening of hexavalent chromium using a HACH test kit.

Table 2-7 presents well development data including final water quality data, and hexavalent chromium field screening results. Included in Appendix B are copies of the field notes documenting well development. These notes include data on water quality parameters and purge volume.

2.3.6 GROUNDWATER SAMPLING

Two sets of groundwater samples collected at the Puchack Site are discussed in this report. The first set of groundwater samples were collected from 13 wells by the USGS between October 1999 and December 1999 (Table 2-8). The purpose of the first limited set of groundwater samples collected from the 13 wells was to obtain data to help scope the larger comprehensive monitoring well installation program. The second set of groundwater samples were collected by the USGS, with assistance from CDM, from 64 newly installed monitoring wells and 24 existing wells between August 2000 and April 2001. The 64 newly installed monitoring wells were sampled approximately one month after they were completed and developed, in order to allow time for the well materials to equilibrate with the surrounding aquifer materials and groundwater. Well construction details for the wells are presented in Appendix D.

Figure 2-3 presents the locations of the monitoring wells from which water quality samples were collected by the USGS between during 1999 - 2001. A list of groundwater samples collected for analyses during the field investigation are presented in Table 2-9. Results of groundwater sampling are discussed in Section 4. QA/QC samples collected in association with groundwater samples are discussed in Section 2.3.7.2.

2.3.6.1 Selection of Monitoring Wells for Groundwater Sampling

The monitoring wells that were sampled were selected based on the following criteria:

- Monitoring wells downgradient of the known contaminant plumes, as defined by 1998 sampling
- Monitoring wells where re-sampling would indicate plume movement
- Monitoring wells where previous analytical results were questionable
- Monitoring wells needed to confirm low levels of contaminants
- Public supply wells that were potential receptors of groundwater contaminants

2.3.6.2 Groundwater Sample Collection Procedures

The USGS, with support from CDM, conducted well purging and groundwater sample collection using a modified low-flow (low stress) pumping method in accordance with the USGS QAPP (USGS 2000) and with the objectives and language of the Method Summary specified in the EPA Region II Low Flow Standard Operating Procedure (SOP). The objective was to collect groundwater samples that were representative of water in the aquifer surrounding the well screen. The modified low-flow procedures were used to minimize sample turbidity by maintaining low entrance velocities at the well screen, thereby reducing the potential for pressure changes or disturbance at the well screen that could induce turbid conditions. Water samples from monitoring wells were collected using a Grundfos Redi-Flo 2 two-inch diameter stainless-steel submersible pump and 3/8-inch inner diameter Teflon®-lined polyethylene discharge tubing. The pump was inserted at least 3 feet into the water column and was placed a minimum of ten casing diameters above the top of the screen to minimize disturbance in the well bore and screen prior to purging and sampling. A minimum of three casing volumes (measured from the pump intake to the bottom of the well) was purged from the well at a rate of less than two gallons per minute to ensure that the water level did not drop more than one foot.

DO concentration, oxidation-reduction potential (Eh), pH, specific conductance (SC), temperature, and turbidity were measured in the field and monitored during well purging. Stabilization of these parameters (except Eh) was used to indicate when the groundwater below the pump intake had reached equilibrium with the aquifer. Samples were collected after the measured parameters conformed to the stabilization criteria, as specified in section of B2.7 of the USGS QAPP (USGS 2000), and once a minimum of three casing volumes had been purged. All of the field-measured constituents and characteristics, excluding turbidity, were monitored with a YSI 6000XL multi-parameter meter. Turbidity was monitored using a Hach 2100P portable turbidity meter.

All samples analyzed for inorganic constituents were collected in an anoxic environment. High-purity nitrogen was fed continuously into the sample-collection bag through a disposable silicon tube. As indicated in Table 2-9, filtered samples were collected for metal analysis at some locations. These samples were filtered with a 0.45-micron Gelman Supor inline capsule filter which were purged with nitrogen immediately prior to sample collection. The nitrogen environment was employed in order to prevent potential iron oxidation and precipitation of ferric iron hydroxide in the sample, a process that could artificially lower concentrations of dissolved chromium through sorption of chromium to the precipitated iron hydroxide particles.

All of the pre-cleaned and pre-preserved sample containers were supplied by the laboratory performing the analyses. The sample bottles supplied for all constituents, except VOCs, were not rinsed. The 40-milliliter VOC vials were rinsed three times and filled with sample water; 1:1 hydrochloric acid was then added to adjust the sample pH to below 2.0. Twenty-three wells were selected to be analyzed for both total and dissolved trace metal samples in 2000-2001. All samples were collected in a dedicated, clean, sampling vehicle (converted cargo van). All of the field equipment used to collect the blank and environmental samples was first cleaned in a laboratory setting using the procedures outlined in the USGS QAPP (USGS 2000). Sampling pumps were completely disassembled, decontaminated and laboratory cleaned under controlled conditions prior to collecting each environmental sample. All of the cleaned equipment was then dedicated to a specific sample, and the tubing, filters and glove bags were disposed of after each environmental sample was collected.

2.3.6.3 Groundwater Sample Chemical Analysis

DECEMBER 1999

Chemical analysis of samples collected between October 1999 and December 1999 were performed at Lancaster Laboratories and the EPA lab in Edison, New Jersey. Samples were analyzed at the EPA laboratory using the following methods from EPA Methods and Guidance for Analysis of Water (MGAW) (USEPA 1997), and Standard Methods for the examination of Water and Wastewater (SMEWW), 18th edition:

- MGAW 524.2 VOCs by gas chromatography/mass spectroscopy (GC/MS)
- MGAW 200.7 Inductively Coupled Plasma (ICP) metals and major ions
- MGAW 245.1 Mercury cold-vapor
- MGAW 415.1 TOC, dissolved organic carbon (DOC)
- MGAW 351.2 Total Kjeldahl nitrogen
- MGAW 353.2 Nitrate+nitrite, nitrite, total phosphorus, ortho-phosphate
- SMEWW 4500-NH₃F Nitrogen as ammonia
- SMEWW 2320B Alkalinity

Samples were analyzed at Lancaster Laboratories using the following reference methods from Standard Methods for the Examination of Water and Wastewater (SMEWW), 18th Edition and Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW846) (USEPA 1986a):

- SMEWW 3500 CR-D, SW846 7196A hexavalent chromium

AUGUST 2000 – APRIL 2001

Samples collected between August 2000 – April 2001 were analyzed by the Electron Microscopy Services Laboratory (EMSL) and Severn Trent Laboratories, Inc. (STL). Samples were analyzed at STL using the following methods from Methods for Chemical Analysis of Water and Wastes (MCAWW) (USEPA 1983) and Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW846) (USEPA 1986a):

- SW846 8260B VOCs by GC/MS
- SW846 6010B ICP metals
- SW846 6020 ICP mass spectroscopy metals
- SW846 7470A Mercury cold-vapor
- MCAWW 353.2 Nitrate/nitrite
- MCAWW 354.1 Nitrite
- MCAWW 350.1 Nitrogen as ammonia
- MCAWW 300.0A Chloride, sulfate
- MCAWW 365.3 Ortho-phosphate, total phosphorus
- MCAWW 415.1 TOC, DOC

Samples were analyzed at EMSL using the following reference methods from Standard Methods for the Examination of Water and Wastewater (SMEWW), 18th Edition and Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW846) (USEPA 1986a):

- SMEWW 3500 CR-D, SW846 7196A hexavalent chromium

Table 2-10 shows the minimum reporting levels (MRLs) for inorganic analytes. MRLs for VOCs varied because the analyte concentrations in some samples were too high for quantification and these samples needed to be diluted for analysis. Table 2-11 compares the methods used for volatile organic analysis of samples collected during the two sampling events.

2.3.6.4 Groundwater Sample Identifiers

In the field, samples were given two different names by either applying “Puchack” in front of the monitoring well location name (e.g., Puchack MW-17I) or by using a coordinate system designated by the USGS (e.g., 395801075030603 Puchack MW-3I).

Groundwater samples collected during the monitoring well groundwater sampling were renamed during data management and identified using the following syntax:

MW99#-Date[-D]

where:

MW	=	monitoring well location (for eight samples this was preceded by “CCWD” indicating Camden City Water Department)
99	=	sequential location number, beginning with 01
#	=	depth designator, six possible values:
D	=	deep
I	=	intermediate
M	=	middle
S	=	shallow
WT	=	water table
EAST	=	east
Date	=	date sample was collected (YYYY-MM-DD)
[-D]	=	duplicate sample

For example the sample identifier “MW15D-2001-02-21” indicates the groundwater collected for the deep monitoring well MW-15D on February 21, 2001.

DUPLICATE SAMPLES

Field duplicate samples are designated in the database with the suffix “-D”.

In the field, the duplicate samples are given the name of the monitoring well along with the word “SPLIT” to identify which is the true sample and which is the blind duplicate. The duplicate samples were renamed during data management when the “SPLIT” duplicate designator was changed and “-D” suffix was appended to indicate a duplicate sample and to make both sample names unique.

Example: “MW-17I-SPLIT” used on the chain-of-custody is the same as “MW-17I-D” in the data base

BLANKS

Trip blank and field blank samples collected during the monitoring well groundwater program were renamed during data management and identified using the following syntax:

FB-MW99#-Date
TB-Date

where:

FB, TB	=	field or trip blank
MW	=	monitoring well location
99	=	sequential location number, beginning with 01
#	=	depth designator, six possible values:
D	=	deep
I	=	intermediate
M	=	middle
S	=	shallow
Date	=	date sample was collected (YYYY-MM-DD)

For example, the sample identifier “FB-MW23D-2001-02-07” indicates a field blank collected at monitoring well MW-23D on February 7, 2001 (02/07/01) and “TB-2000-10-19” indicates a trip blank collected on October 19, 2000 (10/19/00).

In the field, field blank samples were given the name of the monitoring well along with the word “field blank” (e.g., Puchack MW-29S-Field Blank), to identify each sample. The field blanks were renamed during data management to correspond to the monitoring well names.

2.3.7 QUALITY ASSURANCE/QUALITY CONTROL SAMPLING

QA/QC samples collected during the RI field event consisted of field blank samples of deionized water, field blanks (rinsate samples of sampling equipment), trip blanks, duplicate samples, and matrix spike/matrix spike duplicate samples.

2.3.7.1 Soil and Aquifer Sediment Sampling QA/QC Samples

During the soil and aquifer sediment sampling program, duplicate samples and field blanks were collected to assess the reproducibility of analytical results and the adequacy of decontamination procedures.

Field duplicate samples were collected and analyzed to assess the overall precision of the field sampling technique. Collocated grab soil and sediment samples were collected for VOC analysis. Non-VOC duplicate soil samples were collected from two collocated aliquots of soil that were thoroughly homogenized by the EPA-required coning and quartering method (see Section 5.4.3 of the CDM QAPP for the procedure) (CDM 2000b). The split spoon core was divided into samples by cutting the core lengthwise down the middle. Each half represented a separate sample. A VOC sample was collected from each side of the split spoon. The remaining aliquot from each sample was homogenized separately and used to fill the non-VOC sample containers.

Duplicate soil samples were collected at a rate of five percent or one per 20 samples or less. These duplicates were submitted "blind" to the laboratories by using sample numbers that were separate from their associated environmental samples.

One field blank was collected for each equipment type after each decontamination event and was analyzed for the same constituents as the environmental samples. Field blanks, also known as "rinse blanks" or "equipment blanks", are used to assess the effectiveness of equipment decontamination. Field blanks were collected before the use of the decontaminated equipment for sampling. The frequency for field blanks was one per decontamination event, not to exceed one per day, for each equipment type and for each sample matrix. Field blanks were generated by pouring demonstrated analyte-free water over or through the decontaminated sampling tool. The definition of demonstrated analyte-free water can be found in Section 6.8 of the CDM QAPP (CDM 2000b). Field blanks accompanied the set of samples collected by the decontaminated sampling equipment and were kept at 4°C. Daily field blanks of the dedicated core sampler (i.e., En Core™ sampler) used for collecting soil VOC samples were not required.

2.3.7.2 Groundwater Sampling QA/QC Samples

QA/QC samples were collected to evaluate sample contamination and reproducibility and precision of the analysis results. QA/QC samples collected during the sampling period consisted of equipment blanks, field blanks, and trip blanks, as described by Horowitz et al. (1994) and Koterba et al. (1995). Trace metal reference samples were obtained from the USGS Standard Reference Sample Project and sent to the EPA lab and STL for analysis. The equipment used to collect the equipment blank and each field blank was laboratory cleaned under controlled conditions before each sample was taken. Duplicate samples were also collected, following the protocol listed below. Reagent-grade deionized water supplied by the USGS National Water Quality Lab was used for all blank samples. Fifty-one quality assurance samples, excluding trip blanks, were collected in the field during 1999 and 2000-2001.

Equipment blanks were collected in the USGS laboratory under controlled conditions to assess the potential of contamination from sampling and processing equipment. A stainless-steel

Grundfos Redi-Flo 2 submersible pump was laboratory cleaned and used to move certified analyte-free deionized water from a polyethylene standpipe through Teflon®-lined polyethylene tubing and a filter, and into a sample bottle. Two equipment blanks were collected, one before the study period and one in April 2000. These samples were analyzed for the same constituents as the environmental samples.

Field blanks were collected at 21 different sites during the sampling period (October 1999 - April 2001) to assess the potential of contamination resulting from sample collection and preservation under field conditions. Most of the field blanks were analyzed for the same constituents as the environmental samples; one was analyzed for VOCs only, and nutrient analysis was omitted for another (Table 1-1, CDM 2001c). A field blank was collected by placing a Grundfos Redi-Flo 2 submersible pump into a polyethylene standpipe filled with deionized water outside the sampling van. The water was pumped into the sampling van through dedicated Teflon®-lined polyethylene tubing, fittings, and a 0.45 micron filter, and ultimately into a sample bottle. Equipment used to collect the field blank was then used to collect the environmental sample. All blanks were collected prior to collecting the environmental sample.

Duplicate samples are environmental samples that are divided into two or more equal sub-samples, each of which is submitted to one or more laboratories for identical analyses (see Table 6, page 42 USGS 2000). Four filtered duplicate samples were collected in 1999. Nineteen unfiltered and seven filtered duplicate samples were collected in 2000-2001 to assess the precision of analytical results. Because the potential existed for entraining air and allowing analytes to escape from the VOC samples during the splitting process, no VOC duplicates were collected in 2000-2001. The field procedures for collecting quality control samples described in Section 4.3, pages 91-AC 3, Appendix 3 of the QAPP (USGS 2000) do not provide guidelines for performing duplicate samples with pre-preserved bottles, such as those supplied by the analyzing laboratory. Therefore, the following modifications to the procedures were made.

- When collecting unfiltered, water duplicate samples, both the pre-preserved environmental and pre-preserved duplicate sample bottles were filled with sample water and allowed to sit for ten minutes. Both of these bottles were then emptied into a clean, unpreserved 1-liter polyethylene bottle supplied by STL. The 1-liter bottle was then shaken, and poured back into the environmental sample and duplicate sample bottles. A new 1-liter polyethylene bottle was used for each unfiltered, water duplicate sample taken.
- For dissolved (filtered) duplicate samples, a clean, unpreserved 1-liter polyethylene bottle supplied by STL was filled with filtered sample water and poured into the pre-preserved environmental pre-preserved and duplicate sample bottles. A new 1-liter polyethylene bottle was used at each well that dissolved (filtered) duplicate samples were taken.

Trip blanks were used to determine whether shipping, storage, and handling procedures had caused sample contamination. Trip blanks were prepared at the laboratory and shipped in the same coolers as the empty sample bottles. The trip blanks remained unopened in the cooler and were returned with the environmental samples to the laboratory for analysis. During the sampling activities, 10 trip blanks in 1999 and 58 trip blanks in 2000-2001 were analyzed for VOCs.

Reference samples (performance evaluation samples) of known composition were submitted to assess the accuracy and precision of laboratory analytical methods. Two reference samples of different composition were sent to the analyzing laboratories during the study period.

Chain-of-custody procedures were followed during sample handling and shipping. Details of these quality control measures for sample handling and custody requirements are outlined in section B3 of the QAPP (USGS 2000). This section describes the chain-of custody requirements and the procedures of sample handling, packaging and shipping for all samples collected.

2.3.8 WATER LEVEL MEASUREMENTS

Both synoptic and continuous groundwater levels were measured in monitoring and water supply wells located within the study area during 1998-2001. Synoptic water levels were measured in 133 wells in November 1998, and in 182 wells in April 2001. In February 1999, continuous monitoring of water levels began in seven wells equipped with water level data loggers that recorded hourly water levels. In addition, periodic manual water level measurements were collected from seven other wells.

Water levels in the study area are affected by naturally occurring environmental conditions such as recharge from precipitation and tidal effects from the Delaware River, and also by local pumping stresses. Synoptic measurements represent a “snapshot” of water levels in the Potomac-Raritan-Magothy aquifer system under normal pumping conditions, while continuous water level measurements illustrate small fluctuations within the long-term water levels trends.

The wells selected for water level measurements are screened in the Upper, Middle, and Lower aquifers and are listed in Table 2-3, identified with a data-type code “W.” Locations of the synoptic wells are shown on Figure 2-2. Water level measurements were collected in non-pumping wells in order to represent conditions in the aquifers with private and public water-supply wells pumping normally. In addition, water levels affected by pumping were measured at several pumping water-supply wells to determine the lowest possible water level elevations present in and near the pumping wells. Measurements at pumping wells and nearby non-pumping wells provided detailed information about stressed potentiometric heads in the areas surrounding supply wells and relations to regional heads in the three aquifers.

2.3.8.1 Synoptic Water Level Measurements

Synoptic water level measurements provide information to determine horizontal and vertical hydraulic gradients, changes in hydraulic head over time, and calibration points for estimating confining-layer properties and determinations of groundwater flow. Knowledge of aquifer system hydraulic conditions and direction of groundwater flow are key to the understanding of contaminant transport horizontally within the aquifers, and vertically from one aquifer to another through confining layers.

Synoptic water levels were measured in 134 wells in November 1998 and in 183 wells in April 2001. On April 17 and 18, 2001, water level data were collected from the 64 newly installed OU1 RI wells. Water level measurements were made in 119 other wells in the study area from April 17-26. Water level measurements were used to develop equipotential maps for the Middle

and Lower aquifers. The water level data were used to determine horizontal and vertical hydraulic gradients, determine directions of groundwater flow that were evaluated in light of other surface and subsurface hydrogeologic information to develop a comprehensive hydrogeologic conceptual model for the Puchack Site. The groundwater elevation data are presented in Table 2-12. Locations of the monitoring wells selected for synoptic measurements are shown on Figure 2-2.

A surveyor's mark was filed into the top of the inner riser casing of the monitoring wells. Static water levels in the monitoring wells were measured to the nearest 0.01 foot from this surveyor's mark. The measuring point elevations were determined for wells other than monitoring wells by measuring the height of the measuring point relative to a known datum at the well location. Water levels were usually measured directly, either with an electric tape or a steel tape. Measurements were made at least twice at each well in order to verify that results were reproducible. Direct measurements were not possible in three wells measured in 1998 and in these cases water levels were measured by using the owners' airline. No airline measurements were made in 2001. The accuracy of the airline measurements depends on the condition of the airline, accuracy of the pressure gauge, and accurate measure of the airline length, none of which could be verified during the study. At four locations where water levels were affected by pumping, measurements were made under pumping and non-pumping conditions in order to quantify the effect of pumping on water levels.

All water level measurements were referenced to a fixed measuring point, and depth to water below the measuring point was adjusted to sea level on the basis of the elevation of the measuring point. In this report, land surface elevations for surveyed wells are rounded to the nearest 0.1 foot, and the measuring point elevations, determined by the same leveling survey, are rounded to the nearest 0.01 foot. Land-surface elevations derived by methods other than a leveling survey are rounded to the nearest foot. The elevations of measuring points at non-surveyed wells are determined by measuring the distance of the measuring points above or below the estimated elevation of the land surface derived from the most detailed topographic maps available. Results of water level measurements are discussed in Section 3.5.2.2.

2.3.8.2 Continuous Water Level Measurements

Continuous monitoring of water levels began in February 1999. Seven wells at five locations were fitted with pressure transducers and water-level data loggers that recorded hourly water levels, and periodic manual water-level measurements were collected from seven other wells. The wells selected were screened in the Middle and Lower aquifers and the Intermediate Sand layer within the Middle/Lower Confining Unit (Walker and Jacobsen in press). Water levels recorded in these wells were considered to be representative of those surrounding the Puchack well field. The locations of and hydrographs from these wells are discussed and presented in Section 3.

The data loggers recorded hourly water level measurements that were downloaded to a portable computer about every two months for transfer to the USGS National Water Information System (NWIS) database. At that time, the calibration of the data logger was checked against manual water-level measurements made using a steel tape.

In order to supplement the data from the continuous recorders, bimonthly water level measurements were made manually with an electric tape in seven other wells. These measurements provided additional spatial and vertical coverage needed to characterize water level changes over a wider area. As with the synoptic measurements, repeated measurements at each well were made to determine the reproducibility of the water level altitudes.

2.3.9 MONITORING WELL LOCATION AND ELEVATION SURVEY

Elevation and location data used in the OU1 RI was provided by the USGS and by the topographic surveyor, GEOD Corporation (GEOD), under subcontract to CDM.

The land surface elevations given in Table 2-3 are from the USGS Ground-Water Site Inventory (GWSI). This is a computerized data base maintained by the USGS at their office in West Trenton, New Jersey. Elevations documented for wells in GWSI were determined by various methods of differing accuracy and precision. Land surface elevations at some well sites were estimated from a 2-foot contour-interval topographic map (James C. Anderson Associates, Inc. 1996) or were estimated from USGS 7-1/2 minute topographic maps with contour intervals of either 10 or 20 feet. An altimeter was used to determine land surface elevations at a few locations.

The location and elevations at the 64 wells installed during the OU1 RI, 16 ERT soil boring locations, and 23 existing monitoring wells, public supply wells, and observation wells were surveyed by GEOD. The field work was completed from May 31, 2001 through June 13, 2001. GEOD also surveyed an additional 30 existing wells in August 2001 to ensure that all the wells used in the OU1 RI were located relative to the same datum within the Puchack Site. The horizontal datum is the New Jersey State Plane Coordinate System, North American Datum (NAD) 1983 and the vertical datum is the National Geodetic Vertical Datum (NGVD) 1929 for the vertical control. Final surveying data for these wells are listed on Table 2-13.

At each surveyed location the ground surface and measuring point elevations were determined. Small grooves or black marks already present on the inner casing indicated the measuring point. The elevation of the measuring point of each well was determined to within 0.01 feet. The horizontal location of each well was determined to within 0.10 feet. CDM also completed and submitted the NJDEP Form B- Monitoring Well Location Certification.

2.3.10 CONTROL OF INVESTIGATION-DERIVED WASTES

Investigation-derived waste (IDW) including liquid waste (e.g., purge water from wells), waste decontamination fluids (from personal and equipment decontamination), disposable material related to site activities (e.g., used Tyvek® coveralls and gloves), and all semi-solid wastes (e.g., drilling mud and cuttings) were drummed and stored within two staging and storage areas. The first storage area was located on World Harvest Christian Ministries property at the corner of Westfield Avenue and Derousse Avenue. Due to the large amount of IDW generated, a second storage area was created on the Puchack well field property. All IDW was disposed of by CDM's waste disposal subcontractors: Environmental Management and Data Services (EMDS) and Clean Venture.

Large volumes of drilling mud, drill cuttings, and purge water were generated during the drilling and development of the monitoring wells. Drilling mud was stored temporarily in four 5,000 gallon roll-off containers, and purge water generated during the development of the monitoring wells was stored in two 21,000-gallon Baker Tanks. The roll-off tanks and Baker tanks were located at the IDW storage area. Material from the roll-off tanks and Baker tanks were sampled and disposed of by CDM's IDW subcontractor. At the conclusion of the project, the IDW subcontractor was also responsible for removing the sludge and cleaning out the Baker Tanks. Drilling cuttings, stored in labeled 55-gallon steel drums at the IDW storage area, were sampled and subsequently removed by CDM's IDW subcontractor.

Several volatile fuels and solvents were used in small quantities for the field investigation. To minimize the potential for cross contamination of sample containers and analyte-free water, fuels and solvents were stored separately in 55-gallon drums. Waste solvents were disposed of by CDM's IDW subcontractor.

CDM performed field oversight and health and safety monitoring during all waste disposal field activities.

2.4 DEMOGRAPHY AND LAND USE SURVEYS

In an effort to gain a comprehensive understanding of the study area demographics, CDM obtained updated population and land use data from the Pennsauken Township Web Site and the EPA Geographic Information Query System. The results of CDM demographic and land use surveys are presented in Section 3.6.

3.0 PHYSICAL CHARACTERISTICS OF THE STUDY AREA

3.1 TOPOGRAPHY

The topography of the Puchack Site increases gradually, from the area of the Puchack well field, from a low of 10 to 15 feet on the north of the Puchack Site to about 88 feet on the southeast end of the well field. Elevations are relatively low at about 10 to 15 feet above sea level at wells Puchack 1 and Puchack 3/3A. To the southeast the surface elevation increases gradually to 20 to 27 feet at well Puchack 5/5A and well Puchack 6-75/7. Elevations at the Puchack well field reach their maximum of about 48 feet at well Puchack 4R/6. In the larger site area, as defined by the OU1 boundary (Figure 1-2), elevations increase from 10 feet, at well MW-18D near the Betsy Ross Bridge on the western end of the Puchack Site, to about 89 feet at wells MW-35I and MW-35D on the eastern end of the Puchack Site. Over geologic time the Puchack and Pennsauken creeks eroded a low area where the Puchack well field is located today. To the southwest of the well field the topography rises quickly to an elevation of about 60 feet over a distance of about 1,000 feet. To the northeast of the well field the elevation remains relatively low, at about 20 feet, only rising to 60 feet about one mile northeast of the well field. To the southeast of the well field, the topography rises slowly in the area where a number of small tributaries to Puchack Creek occur. The elevation reaches 60 feet about 1.5 miles southeast of the Puchack Site.

3.2 METEOROLOGY

Climate data were obtained from Philadelphia which is located within 10 miles to the southwest of the Puchack Site. Data were available for the period from 1820 to 1930 and from 1942 to 1993. Table 3-1 summarizes the climatic data in the vicinity of the Puchack Site. The average temperature calculated for the Puchack Site area in January was 30.4° Fahrenheit (F). The average temperature in June was 71.8° F. The annual mean temperature was 54.4° F. Over the recording period the average annual rainfall was 41.41 inches.

3.3 SURFACE WATER HYDROLOGY

The site lies within the Lower Delaware Watershed, Watershed Management Area 18 as defined by the NJDEP (USGS Cataloging Unit: 02040202). There is no prominent surface water body within the Puchack Site boundary. The surface water hydrology near the Puchack Site is dominated by the Delaware River, northwest of the Puchack Site, which flows from the northeast to the southwest (Figure 1-2). Puchack Creek is located immediately to the north of the Puchack Site. This stream flows northwest to the Delaware River. This stream has been significantly altered by road building and flows in a culvert over a significant portion of its run and parallels Route 93, which runs over the Betsy Ross Bridge into Pennsylvania. Puchack Creek provides storm water drainage for the surrounding areas, which include a portion of Puchack site. Puchack Creek received Puchack well effluent and will be the subject of a limited investigation under OU2.

Another significant surface water body in the vicinity of the Puchack Site is Pennsauken Creek which lies over a mile to the northeast of the Puchack Site. This stream flows northwest and discharges into the Delaware River near Palmyra, New Jersey (Figure 1-2). According to the

NJDEP, the Pennsauken Creek drains 33 square miles of southwestern Burlington County and northern Camden County (NJDEP 2002). Just southeast of the intersection of Routes 73 and 130, the Creek splits into north and south branches. The North Branch of Pennsauken Creek is in Burlington County, while the South Branch is the boundary between Burlington and Camden Counties. Industry is concentrated at the mouth of Pennsauken Creek. Much of the watershed is developed urban/suburban, with the remainder divided between agriculture and forested land.

3.4 REGIONAL GEOLOGY AND HYDROGEOLOGY

3.4.1 REGIONAL GEOLOGY

Sediments of the Coastal Plain in Maryland, Delaware, and New Jersey range in age from Cretaceous through Quaternary, and lie unconformably on weathered basement rocks of Precambrian, early Paleozoic, and Triassic age. They form an eastward-thickening wedge that is composed of unconsolidated and partly consolidated sediments formed in shallow marine, deltaic, and fluvial depositional environments (Owens and Sohl 1969). During Pleistocene time, dissection of the uppermost beds by streams and rivers led to the present topography, which, in the central and western part of the New Jersey Coastal Plain, consists of uplands that slope eastward to the Atlantic Ocean and westward to lowlands along the Delaware River. These lowlands are thought to have been created through down cutting by a large river, the course of which ran parallel to the inner boundary of the Coastal Plain (Owens and Sohl 1969). Cretaceous sediments of the Potomac Group, Raritan, and Magothy Formations are thus exposed along part of the course of the present-day Delaware River and along the Fall Line.

3.4.2 REGIONAL HYDROGEOLOGY

The Potomac-Raritan-Magothy aquifer system is composed of the wedge-shaped sequence of sediments of the Potomac Group and the Raritan and Magothy Formations. These sediments constitute sand and gravel aquifers with intervening silt and clay confining units that thicken and dip from the western edge of the Coastal Plain at the Fall Line toward the southeast (Zapczynski 1989). The sediments are of fluvial-deltaic-marginal marine origin (Farlekas et al. 1976), and are indicative of a complex depositional and erosional environment. The basal unit of the Potomac Group lies directly on the erosional, pre-Cretaceous bedrock surface.

Farlekas et al. (1976) divided the Potomac-Raritan-Magothy aquifer system in the Camden County area into five layers (Figure 3-1) described as Upper, Middle, and Lower aquifers separated by two confining units. As seen in Figure 3-2, the Upper aquifer consists of sands of the Magothy Formation, and the Middle and Lower aquifers are composed of sands of the Raritan Formation and Potomac Group. Figure 3-3 shows the location of the wells used by the USGS to define the hydrostratigraphic framework at the Puchack site. These sediments crop out as thin bands along both sides of the Delaware River in Pennsylvania and New Jersey, and are exposed in the bed of the Delaware River through fluvial dissection and through dredging. Recharge to the aquifer system is primarily through incident precipitation on the outcrop areas and from the Delaware River and surface water bodies where they intersect the aquifer system. In downdip areas to the east, the sediments that compose the Potomac-Raritan-Magothy aquifer system are overlain by successively younger Cretaceous and Tertiary sediments. Thus, the aquifer system is confined over much of its extent, and recharge to downdip areas is through

groundwater flow from outcrop areas and leakage from overlying units.

3.5 SITE GEOLOGY AND HYDROGEOLOGY

The study area, shown on Figure 1-2, is situated within Pennsauken Township. It has been extensively urbanized; consequently, some of the soil cover discussed below bears little relation to the geologic substrate upon which it lies. Nevertheless, the properties and composition of the existing soils are important because it is through these soils that contaminants have passed from the land surface to the groundwater. The lithology of the undisturbed geologic substrate is important because of the potential for interactions between minerals composing the soils and/or the underlying geologic sediments and those contaminants introduced at or near the surface that may reach the groundwater system. The discussion of the lithology that follows considers those materials that can participate in geochemical reactions with introduced contaminants. The nature and stratigraphy of the sediments are closely connected to the hydrologic properties of the aquifer system they form; consequently, the hydrogeology, which includes the study area geology, is discussed below, with a detailed presentation of the newly delineated hydrostratigraphic framework. The section concludes with a description of local groundwater levels, water level trends and flow patterns.

3.5.1 SITE SOILS AND GEOLOGY

Because the study area is almost entirely urban land, the original soils have, in some instances, been replaced with soil and sediment from elsewhere. Indigenous soils commonly have been disturbed and soil series typical of the area, such as Freehold, Downer, Holmdel and Howell, generally have been mapped as urban land complexes (Markley 1966). Downer and Freehold soils are loamy sand or sandy loam; Freehold soils typically contain glauconite. The Holmdel and Howell soil series, where these occur, also contain glauconite. Soils are composed largely of quartz sand; quartzose gravel layers occur, commonly, but not always, in B- or C-horizon soils. Some Freehold and Downer complexes are developed on a clayey substratum. As a consequence, some sandy soils are well drained, but those containing or underlain with clays drain relatively poorly. Loamy alluvial soils are present along Puchack Creek, and tidal marsh soils with “made” land occur along the upper reaches of Pennsauken Creek.

On the basis of pH measurements made during an early phase of the present study, the soils of Pennsauken Township range from very strongly acidic (4.6) to moderately alkaline (8.3) (CDM 2001a). The soil series were not identified for the soil samples collected during the earlier phase of this study, but soils are described as generally sandy, with some silts and clays. Surficial soils appear disturbed in some instances; the colors of subsurface soils typically are described as yellow, brown, or red-yellow, indicating that these are B-horizon soils with iron hydroxide coatings on the sand grains. The minimally weathered C-horizon soils in the study area generally are encountered at about 3-4 feet bgs (Markley 1966). The recent soil sampling extended well into the unsaturated aquifer sediments, typically to the water table. Descriptions of these deeper samples are included in the next section.

The oldest unconsolidated sediments in the area are sands and gravels of the Potomac Group which lie unconformably upon weathered mica schist or clays, the latter presumably derived from the schist. Sediments of the Potomac Group are interbedded sand, clayey silt, and silty clay.

The overlying Raritan Formation is composed of interbedded light-colored sands and red, white, or yellow silty clays (Owens and Sohl 1969). The quartzose sands of both formations contain micas (muscovite and biotite) and lignite; lignite is also present in clay layers. Clays are predominantly kaolinite, with some illite and mixed-layer clays present. Montmorillonite also is reported. Other minerals include goethite and a mica-glaucanite mixture (Owens and Sohl 1969).

The youngest of the Cretaceous sediments in the study area is the Magothy Formation, which is composed of light-colored quartzose sands and lenses of dark clay. Clays are kaolinite, illite, and mixed-layer; montmorillonite and vermiculite are reported in some samples (Owens and Sohl 1969). Lignite is present, in some cases as thin layers.

The outcrops of the Cretaceous deposits in the Inner (western) Coastal Plain are overlain unconformably by younger sediments in many areas. Pennsauken Township is a type location for one of the Tertiary Coastal Plain deposits, the Pensauken (old spelling) Formation of Late Miocene age. The Pensauken Formation is composed of sands and coarse gravels in the study area. Iron-cemented feldspathic sands overlie thin beds of reworked glauconite sand. The weathered gravels of the Pensauken Formation are arkosic, containing weathered crystalline and metamorphic rocks, sandstones and shale, as well as quartz, quartzite, and chert (Owens and Minard 1979). Overlying Quaternary deposits of Pleistocene age are composed of gravels, greywacke sand, and clayey silt, which probably are, in part, reworked materials from morainal deposits (Owens and Minard 1979).

The USGS analyzed the mineralogy of 13 aquifer sediment samples from monitoring well borings completed at the site. The results are summarized on Table 3-2. Four of the samples were characterized as non-magnetic heavy minerals, three as clay and silt, three as sand, one as sand and silt, one as semi-magnetic heavy minerals and one as a gravel sample. All the non-magnetic heavy mineral samples were composed primarily of kyanite (>50%). Minor minerals in these samples included rutile, sphene, zircon, and tourmaline. The three clay and silt samples were composed mainly of kaolinite. Lignite was observed in one of the clay and silt samples. The sand samples and sand and silt sample were composed primarily of quartz. Lignite was observed in three out of the total of four of these samples. The gravel sample was also composed primarily of quartz but it was the only sample where orthoclase, plagioclase, and amphibole, were observed. The semi-magnetic mineral sample was unique in that the only mineral identified in the sample was goethite.

3.5.2 SITE HYDROGEOLOGY

In Pennsauken Township and vicinity, permeable layers of sand and gravel of the Pensauken Formation and Quaternary deposits cap most of the extent of the outcrops of the Cretaceous sediments that form the Potomac-Raritan-Magothy aquifer system (Owens and Denny 1979; Farlekas et al. 1976). Sands and gravels of the Pensauken Formation are believed to have been deposited in a fluvial environment in which a series of down cutting channels were incised into the sediments below (Owens and Minard 1979). The Quaternary deposits grade from gravels and gravelly sand at Trenton to clayey silt at Philadelphia; the variability in these deposits probably represents a change in depositional environment from fluvial through deltaic to estuarine. The Tertiary and Quaternary surficial units, which are of variable thickness, are hydraulically connected to the underlying Cretaceous sediments and, therefore, are considered to be part of the

Potomac-Raritan-Magothy aquifer system. The Potomac-Raritan-Magothy aquifer system receives recharge through surface infiltration of precipitation on the outcrop areas, and from the Delaware River, Pennsauken Creek, and other local surface water bodies that are present in the outcrop areas.

Because of the fluvial/deltaic depositional environment of the sediments that compose the aquifer system, discontinuities in individual units are common. Throughout the thickness of the Cretaceous sediments, channels have been cut and filled. Thus, major confining units and aquifers can contain either sand lenses that are local water-bearing zones or clay lenses that serve as local confining units. Major confining units also are found to pinch out in some areas. As a result, the hydraulic connections between the sedimentary units are complex.

3.5.2.1 Hydrostratigraphic Framework

A more detailed structural framework of the five-layer Potomac-Raritan-Magothy aquifer system in Burlington, Camden, and Gloucester Counties (Navoy and Carleton 1995) was built on the regional hydrogeologic framework of the Potomac-Raritan-Magothy aquifer system in the New Jersey Coastal Plain, defined by Zapecza (1989). Walker and Jacobsen (in press) used geologic and geophysical data from 26 new monitoring wells drilled in 1997 to build on the commonly accepted five-layer aquifer system model described by Farlekas et al. (1976). The previously delineated Middle and Lower aquifers and their intervening confining units were subdivided to account for some of the apparent structural variability of the confining units and aquifers, and to provide additional detail needed for groundwater flow and contaminant transport modeling purposes. The subdivided hydrostratigraphic framework by Walker and Jacobsen (in press) is shown in Figure 3-1 together with the five-layer framework developed by previous investigators. The subdivided framework provides the foundation for the more detailed framework developed during this study.

As shown in Figure 3-1, the Upper Potomac-Raritan-Magothy aquifer and the underlying confining unit correlate directly with layer A-1 and layer C-1 respectively. Subdivisions to the five-layer framework by Walker and Jacobsen (in press) included dividing the Middle aquifer into two sand layers, A-2a and A-2b, separated by a thin, discontinuous confining layer, A-2C1. The confining unit separating the Middle aquifer layers from the Lower aquifer was subdivided from top to bottom into an upper clay unit, C-2a; an Intermediate Sand layer, C-2AI; and a lower sandy/silty clay unit, C-2b. (Previous investigators have included the Intermediate Sand (C-2AI) as part of the Lower aquifer in some locations where the C-2b confining unit is sandy.) The Lower aquifer was subdivided into three zones that are characterized from top to bottom as a silt-clay-sand sequence (layer A-3a), a sand-and-gravel zone (layer A-3b), and a very coarse gravel zone (layer A-3c) (Walker and Jacobsen, in press). The confining unit beneath the Lower aquifer (layer C-3) acts as the basal confining unit for the Potomac-Raritan-Magothy aquifer system and is represented by either the pre-Cretaceous bedrock surface or a clay unit lying directly on the bedrock.

Walker and Jacobsen (in press) determined that all three aquifers and the separating confining units contain local, discontinuous sand and clay lenses. In some instances, these individual minor units cannot be traced over distances as short as a few hundred feet as illustrated in Figure 3-2. The identified confining units typically exhibited varying thicknesses and hydraulic properties. The discontinuities in these units likely result in both local structural barriers to transport and local pathways for contaminant transport through hydraulic connections over relatively short distances (Walker and Jacobsen, in press).

The additional information acquired during the well-drilling phases of the present study has indicated a need for further refinement of the hydrostratigraphic framework described by Walker and Jacobsen (in press). Changes to the interpretation of the framework are described below. Nine vertical sections (A-A' through I-I') across the study area were used to correlate the hydrostratigraphic units both spatially and vertically (Plate 2). One section (A-A') is oriented at an oblique angle to strike along the general path of groundwater flow, as described by Walker and Jacobsen (in press). Four of the sections (B-B', C-C', H-H', I-I') are oriented roughly perpendicular to strike, and the other four sections are oriented roughly parallel to strike. Records of wells used to describe the framework are listed in Table 3-3. Some of the control points listed in Table 3-3 were interpreted by Zapecza (1989) and Navoy and Carleton (1995), permitting the detailed framework described for the study area to be correlated with the previously published regional investigations of Coastal Plain sediments. Locations of the 93 wells used to describe the stratigraphy of the study area are shown on Plate 2.

Geophysical log suites, including electric, caliper and natural gamma logs (predominantly natural-gamma logs), were used extensively with subsurface lithologic information obtained from locations of the 64 wells drilled in the study area to correlate units along the lines of section. The geophysical log suites, completed at 27 locations, are included in Appendix C. Geologic materials described in drilling logs were compared with the geophysical logs, and the depths to the tops of significant hydrostratigraphic units were determined. The altitudes of the tops of the hydrostratigraphic units were calculated on the basis of land-surface elevations obtained from the USGS GWSI file, rounded to the nearest foot. The hydrostratigraphic sections were plotted from data points projected to the lines of section shown on Plate 2. Using data from selected wells, the altitudes of the tops of stratigraphic units were plotted on the sections and connected graphically with a line representing the generalized elevation of the top of each unit. In the areas where individual units crop out, the altitudes of the tops of units are considered to be equal to the land-surface elevations. The hydrostratigraphic sections developed were used to refine all interpretations of the tops of these units throughout the study area. The altitude of the top of each hydrostratigraphic unit was used to prepare the structure-contour maps presented in Appendix E. Land-surface elevations were used to define the structural contours in those areas where the shallower units crop out.

The contours of the structural tops of those units that are mostly or wholly subsurface indicate that the tops of all units most likely have complex erosional surfaces. The complexity is most evident in the vicinity of the Puchack well field where there is a greater density of wells and, therefore, geophysical and lithologic logs to define the stratigraphy in greater detail. With increasing depth, the tops of units also reflect the structure of the underlying bedrock surface. The existing data indicate that a bedrock structural high exists near the Morris well field and partly beneath the Pennsauken Landfill. In the vicinity of the Puchack well field, a channel in the

bedrock is evident that traces the general orientation of the present day Puchack Creek. Just southeast of the Puchack well field, a broad ridge in the bedrock trends to the east.

The latest interpretation of the hydrostratigraphic framework is consistent with that described by Walker and Jacobsen (in press). The framework defined by this study is based on the previous work and that data collected during the present study and includes the following significant findings. Figure 3-3 shows the locations of wells used to describe the hydrostratigraphic framework of the Potomac-Raritan-Magothy aquifer system.

- As described previously, the Upper Potomac-Raritan-Magothy aquifer and the underlying confining unit correlate directly with layer A-1 and layer C-1 respectively (Figure 3-1). Layer A-1 contains clay lenses throughout its extent. The clays of confining unit C-1 do not extend throughout the thickness of the unit as a result of cut and fill. As shown on Figure 3-2, C-1 clays are largely absent in the area of well cluster CCWD MW-1 (CC MW-1D on Figure 3-2) and cluster MW-14 [Puchack (P) MW-14I and P MW-14D on Figure 3-2], where the unit is composed mostly of sands. In this area, the sands of the Upper aquifer may be hydraulically connected directly to the sands of the Middle aquifer. Confining unit C-1 is thin and effectively absent in the area near the western edge of the Pennsauken Landfill.
- The Middle aquifer is divided into two sand layers (A-2a and A-2b), separated by a thin, discontinuous confining layer (A-2C1) of variable composition. In the area encompassed by the chromium contaminant plume, cut and fill at the top of the Middle aquifer at well cluster P MW-1 (located on the SGL Chrome property) has created about 25 feet of silty clays with lenses of silt, sand, and fine gravel that penetrate layer A-2a and confining unit A-2C1 into a thin (5-foot) sand layer, A-2b. To the east and down dip, layer A-2C1 is of variable composition at well cluster P MW-26; it is composed of silts and sand with some lenses of clay, reflecting another area of cut and fill. Farther down dip, at cluster CCMW-1, layer A-2C1 is almost entirely sand (Figure 3-2).
- The confining unit separating the Middle aquifer layers from the Lower aquifer is subdivided from top to bottom into an upper clay unit, C-2a; an Intermediate Sand layer, C-2AI; and a lower sandy/silty clay unit, C-2b. The Intermediate Sand is physically separated from both the Middle and the Lower aquifers by the confining units C-2a and C-2b, respectively, in most parts of the study area; it is, however, hydraulically connected to both aquifers in several areas. Northwest of the Puchack well field near the Delaware River, both confining units, C-2a and C-2b, pinch out. In an area contained within the contaminant plume in the Intermediate Sand, layer C-2a clays thin from about 28 feet at well cluster P MW-26 to lenses less than 8 feet thick interspersed with sands at well cluster P MW-14. Between these two clusters, at well cluster CCMW-1, C-2a becomes a 22 foot silt and clay unit with some fine sand layers. Lower layer C-2b clays thin to lenses less than 2 feet thick interspersed with sands and silts at well cluster MW-27; the lenses are only slightly thicker (less than 4 feet) at well clusters CCMW-1 and MW-14 (Figure 3-2).

- The Lower aquifer was subdivided into three zones that were differentiated based on distinctive grain-size textures. These zones generally grade into each other; however, in some locations, thin clay layers mark their contacts (Figure 3-2). The zones were characterized from top to bottom as a silt-clay-sand sequence, a sand-and-gravel zone, and a very coarse gravel zone. These zones were identified in the framework as layers A-3a, A-3b, and A-3c, respectively. Sandy or silty clay lenses, some areally extensive, are common in layer A-3a. Clay lenses occur sporadically in layer A-3b. The gravelly layer A-3c persists throughout much of the study area, but apparently pinches out in the area of the Morris well field, where there is a bedrock high.
- The confining unit beneath the Lower aquifer is referred to as layer C-3, as before, and consists of clays derived from the weathered schist bedrock or the weathered bedrock itself.

3.5.2.2 Groundwater Levels and Flow

Groundwater levels and flows in the study area are controlled by the sustained pumping of the Middle and Lower Aquifers, recharge from precipitation, and from the tide-influenced Delaware River. To a large extent, pumping at the many water supply well fields influences local groundwater flows and water levels. The spatial and vertical extent to which water levels are affected by recharge and pumping is in part a function of the complex hydrostratigraphy and proximity to a pumping center. In the study area, these conditions result in variable hydraulic gradients that control the flow of groundwater throughout the aquifer system. Knowledge of the hydraulic gradients and groundwater flow within the aquifer system is essential to understand the contaminant-transport conditions and to develop an effective groundwater remediation strategy. This section examines water levels measured at well locations during November 1998 and April 2001. Water levels observed in both 1998 and 2001 are compared and head-change values are calculated. Potentiometric surface maps for April 2001 are used to describe the distribution of hydraulic head in the Upper, Middle and Lower Potomac-Raritan-Magothy aquifers. Groundwater flow, hydraulic gradients, and water-level trends are also examined.

The outcrop of the Upper aquifer, the least used of the Potomac-Raritan-Magothy aquifers in the vicinity of Pennsauken Township, covers a large part of the study area. Unconfined conditions generally prevail in this part of the aquifer. The Upper aquifer is unsaturated in the vicinity of the Puchack well field as a result of the downward movement of water caused by pumping from the underlying, more heavily used aquifers. Where the Upper aquifer is unconfined and saturated, water levels are variable, indicating that, locally, perched conditions may occur (Walker and Jacobsen, in press).

In the Middle and Lower aquifers, groundwater is present under water-table conditions in the outcrop areas and changes gradually to artesian conditions in areas to the southeast where the aquifers are confined. In Pennsauken Township and vicinity, over 98 percent of the groundwater is pumped from the Lower aquifer (Walker and Jacobsen, in press). Most of the recharge in areas closest to the Delaware River reaches the Lower aquifer from the river. Farther to the southeast, proportionately larger amounts of recharge reach the Lower aquifer through vertical leakage

from the overlying Middle aquifer. Leakage from the confining units between the major aquifers, including the C-1 confining unit, leads to the unsaturated conditions in the Upper aquifer described above.

Synoptic water level measurements were collected in November 1998 from 133 wells (Plate 1) and in April 2001 from 182 wells (Figure 2-2). These data are presented in Table 2-121. During the April 2001 synoptic measurement round, water levels from 108 of the wells measured in November 1998 were measured again and head changes in the aquifer system over the period between the two synoptic measurements were calculated. The observed head changes for the 108 wells indicate a general increase in head of over 2 feet in all aquifers (Table 2-12).

In the Upper aquifer, only five head-change values were available; these ranged from 2.08 feet to 9.04 feet, with an average of 5.35 feet. The smallest head-change value (2.08) was associated with a monitoring well. The larger head-change values were associated with wells close to pumping wells; therefore, heads at these wells were subject to large variations as a result of intermittent pumping stresses. In the Middle aquifer, head changes ranged from 0.74 foot to 10.98 feet, with an average rise in head of 2.63 feet for 36 wells. Head changes in the Lower aquifer ranged from -6.14 feet to 7.27 feet, with an average rise in head of 1.99 feet for 68 wells.

Plate 3 illustrates hydrographs prepared from water-level monitoring records for the period February 1999 through June 2001. The monitoring well locations and well depths are spatially distributed to provide relevant hydrographs within the area encompassed by the planned flow model boundary. Table 3-4 describes the monitoring wells whose hydrographs are presented in Plate 3.

The water-level hydrographs shown on Plate 3 generally illustrate a rising trend in water levels in the study area beginning about August of 1999. This trend is consistent with head changes observed in the synoptic water-level measurements throughout the study area. Because the Delaware River is a significant recharge boundary, hydrographs of wells such as Puchack MW-2D that are close to the river indicate a smaller rising trend than do the hydrographs of wells farther from the river such as Puchack MW-12M. The hydrographs also show tidal influences near the river and seasonal variations due to typical pumping stresses superimposed on a steadily rising water-level trend. This rising water-level trend appears to be the result of the mandatory restrictions on pumping of groundwater in the local Water Supply Critical Area; these were required by the NJDEP in response to excessive withdrawals that threatened the long-term integrity of the aquifer system.

A comparison of the heads in the Upper aquifer with those in the underlying Middle aquifer indicates the presence of a downward hydraulic gradient between these aquifers; however, data for the Upper aquifer are limited and therefore are insufficient to make a direct comparison of heads at a common location.

The head relationships between the aquifers and (or) the subdivided lithologic layers are best illustrated by several of the hydrographs shown on Plate 3. At the MW-5 well cluster the hydrographs show the heads in Middle aquifer well MW-5M consistently about 2 feet higher than those in the Intermediate Sand well MW-5I. This condition indicates that the confining unit C-2a is effective in restricting vertical flow between the Middle aquifer and the Intermediate Sand in this area. Conversely, the hydrograph for well MW-5D shows that water levels in the Lower aquifer are consistently slightly lower than those in well MW-5I, indicating that the Intermediate Sand layer is poorly isolated from the underlying Lower aquifer by the intervening confining unit C-2b. Similarly, at the MW-9 cluster, a slight but consistent downward gradient between well MW-9S in layer A-2a and well MW-9M in layer A-2B indicates a good hydraulic connection across the A-2C1 confining unit. The heads in well MW-9D are about 2 feet lower than those in MW-9M, indicating that the C-2a and C-2b confining units are effective in restricting vertical flow between the Middle aquifer and the Lower aquifer in this area.

Based on the synoptic water-level data, the heads in the Middle and Lower aquifers indicate a downward hydraulic gradient between these aquifers. Heads in the Intermediate Sand and the Lower aquifer are similar; thus, at most locations where water-level measurements were made in wells in both units, a small downward hydraulic gradient was usually observed. The head difference between the Intermediate Sand and the Lower aquifer is so small that slight head changes in either of these units appear to cause an occasional reversal in the hydraulic gradient, as indicated by the synoptic water-level data shown in Table 2-12.

A potentiometric-surface map was not prepared for the Upper aquifer for April 2001 because a limited number of wells are screened in the Upper aquifer in the study area. Only five water-level measurements were available and four of these five measurements were made in the confined part of the aquifer. Although these measurements were not sufficient to prepare a reliable potentiometric-surface map, the water-level altitudes and well locations for the Upper aquifer are shown on Figure 3-4. These measurements, although limited, provide important water-level information in the confined, downdip parts of the aquifer and allow comparisons with potentiometric heads in the underlying Middle aquifer.

Potentiometric-surface maps of the Middle and the Lower (including the Intermediate Sand) Potomac-Raritan-Magothy aquifers are shown in Figures 3-5 and 3-6, respectively, and were prepared from synoptic water-level measurements made during April 2001. The potentiometric contours were interpreted, in part, on the basis of knowledge of the relative accuracy of the water-level measurements. The positions of the potentiometric contours were estimated, for the most part, using static water levels in wells. Water levels near pumping centers, however, were estimated on the basis of stressed water levels (shown in blue on Figures 3-5 and 3-6) in and near pumped wells and the knowledge of the local pumping well distribution at the time of the measurement. The potentiometric-surface map, Figure 3-6, for the Lower aquifer includes head data for the Intermediate Sand, because the two units clearly are connected hydraulically.

Groundwater in the Upper, Middle and Lower aquifers generally flows to the southeast, but well fields in the study area control local groundwater flow directions. The lowest potentiometric heads in the aquifer system are centered on large cones of depression in the Upper, Middle, and Lower aquifers about six miles southeast of the study area (Lacombe and Rosman 1997). The Middle aquifer is little used in the study area; therefore, its potentiometric surface (Figure 3-5)

reflects the combined effects of the regional cones of depression in the Middle and Lower aquifers (Lacombe and Rosman 1997) and the downward hydraulic gradient between the Middle and Lower aquifers. Local areas of depressed water levels in the Lower aquifer (Figure 3-6) are centered at well fields operated by the City of Camden and the Merchantville-Pennsauken Water Supply Commission.

In the Middle aquifer the orientation of the potentiometric contours has changed little since March of 1998 (Walker and Jacobsen, in press). Accordingly, the direction of groundwater flow generally remains in a southeasterly direction as illustrated by the flow arrows shown in Figure 3-5. Flow directions in the vicinity of the Puchack well field are generally in a more easterly direction. In this area, and to the north, groundwater flow direction varies locally from northeasterly to easterly to southeasterly as influenced by the local recharge conditions and losses from vertical leakage induced by nearby pumping in the Lower aquifer. Water levels also indicate some influence from pumping in the underlying Lower aquifer in the up-dip areas near the active Morris and Delair well fields. These well fields are generally located in the outcrop of the Middle aquifer but are screened in the Lower aquifer.

In the Lower aquifer, local flow directions have changed in the vicinity of the Puchack well field since pumping ceased in 1998. Although the effects of pumping from the National Highway wells and those at the Morris and Delair well fields can be seen in current water levels, flow in the vicinity of the Puchack well field generally has shifted more to the southeast rather than toward that well field. As with the Middle aquifer, the increased density of wells also affords a more detailed look at the groundwater flow directions locally. Groundwater flow in the down dip areas of the Lower aquifer is generally unchanged since 1998.

3.6 DEMOGRAPHICS AND LAND USE

The Puchack well field is located in Pennsauken Township, Camden County, New Jersey. The well field is owned by the City of Camden and is located between the Betsy Ross Bridge and State Route 90 on the north, a residential area to the south, the Delaware River to the west, and U.S. Route 130. The area encompassed by the well field is approximately 450,000 square feet, or 10.33 acres (Figure 1-1).

There are no known private potable wells in use that have been impacted by the area-wide groundwater contamination defined by OU1. Drinking water for a majority of residents of Camden City is provided by the Camden City Water Department; the remaining portion of the city is served by the New Jersey American Water Company.

Based on 2000 census data retrieved from the U.S. Census Bureau Web Site, Camden County has a total population of 508,932; whereas, Pennsauken Township has a population of 35,737.

Land use in the vicinity of the well field is residential, commercial, and industrial. Several hundred single and multi-family residential buildings, commercial buildings, and industrial facilities are located within a two-mile radius of the Puchack Site. One section of the Pennsauken Industrial Park is located approximately one-half mile to the northeast of the Puchack Site, while another section of the industrial park is located approximately one-quarter mile to the southwest. Conrail railroad tracks are situated approximately 500 feet to the northeast and southeast of the

well field and the tollgate for the Betsy Ross Bridge (Route 90) is located approximately 250 feet to the east. Pennsauken Landfill, the largest man made feature nearby, is less than one mile to the northeast of the Puchack well field.

Pennsauken Township has an aggressive economic development and housing program. Three areas of the Township have been targeted for redevelopment:

- Delaware River Waterfront: The area stretches from the Camden border at 36th Street north to Palmyra. River Road, which runs parallel to the river, serves as the eastern border. The area is almost exclusively industrial. The Township has received a \$200,000 federal grant to investigate the area's environmental conditions as well as a \$50,000 economic development grant from the Camden County Freeholders to help fund a market feasibility study. The former ABarry Steel facility, located next to SGL at the intersection of River and Cove Roads, was acquired by the township as part of this economic development and housing program.
- Crossroads (Intersection of Routes 130 and 73): The area borders the Route 130 corridor in Burlington County which is the subject of a targeted economic development project undertaken by Burlington County officials. The study will measure the potential for more attractive and productive commercial uses. The study is being funded through an economic development grant from the Camden County Board of Freeholders.
- Route 130: Route 130 will be examined for redevelopment potential and aesthetic improvements. The Township has applied for a State Smart Growth grant to fund such a study.

Swope Oil & Chemical Co., another EPA Superfund site, is located in an industrial area in northern Pennsauken Township. A complete listing of known contaminated sites in the area around the Puchack Site will be provided as part of the OU2 investigation.

4.0 OCCURRENCE AND DISTRIBUTION OF CONTAMINANTS IN SOILS, AQUIFER SEDIMENTS, AND GROUNDWATER

4.1 INTRODUCTION

Due to the nature and complexity of the contamination at the Puchack Site, the primary focus of the OU1 RI is to define the extent of chromium contamination in groundwater. Based on prior investigation results, chromium was found in groundwater from three water-bearing units that include two of the three commonly recognized aquifers of the Potomac-Raritan-Magothy aquifer system—the Upper, Middle, and Lower aquifers—as well as the local but areally extensive Intermediate Sand. The configurations of areas of contaminated water—contaminant plumes—differ among the water-bearing units, as a result of differing source areas, hydraulic connections, and types of contaminants present.

While VOCs hot spots were encountered within the boundaries of the Puchack Site chromium plume, coherent VOC plumes have not been identified. Within the vicinity of the Puchack Site the VOC hot spots that were encountered during the OU1 RI have commingled with the chromium plume. VOC hot spots outside of the Puchack chromium plume are not included in the scope of the Puchack Site OU1 RI. The VOCs appear to have been released from several source areas. A hot spot is a well where a VOC exceeded its MCL in a water sample.

The identification and investigation of chromium source areas and any associated VOCs will be completed as OU2 (a separate operable unit). However, as part of the OU1 RI, some soil and aquifer sediment samples were collected from potential source areas and monitoring well locations to aid in the groundwater investigation effort. The soil and aquifer sediment investigation results are also discussed in this section. In some cases, the limited soils data indicate likely sources of contamination; in other cases, the distribution of contaminants in the groundwater indicates possible surficial source areas that need to be investigated. The issue of possible sources will, therefore, be reserved for discussion at the end of this section.

4.1.1 SCREENING CRITERIA

Both inorganic and organic contaminants are present in soils, aquifer sediments, and groundwater in Pennsauken Township in the vicinity of the Puchack well field. Screening criteria were selected to evaluate the potential contamination in each medium.

The screening criteria for contaminants in soils/aquifer sediments and groundwater are presented in Tables 4-1 and 4-2, respectively. Table 4-1 contains the New Jersey Non-Residential Direct Contact Soil Cleanup Criteria (NRDCSCC), the appropriate criteria for surface soils in the industrial and commercial settings, and the New Jersey Impact to Groundwater Soil Cleanup Criteria (IGWSCC) for those inorganic and organic contaminants present in the study area; the table also contains the EPA General Soil Screening Level, Migration to Groundwater, Dilution-Attenuation Factor of 1 (SSL-1DAF), which assumes no dilution of contaminants, for selected constituents in subsurface soils. Ecological values are not used in this table due to a lack of habitat and lack of soil samples that are representative of areas accessible to receptors. These values will be included in the ecological risk assessment as part of OU2.

Table 4-2 contains both New Jersey and EPA Primary Drinking Water Standards, which are composed of MCLs, as well as New Jersey Groundwater Class II-A standards, which are for protection of potable water sources. The chromium-contaminated groundwater that forms several chromium plumes is roughly defined by 100 µg/L chromium isoconcentration lines based on the year 1999-2001 groundwater results.

4.1.2 BACKGROUND CONCENTRATIONS OF CONSTITUENTS IDENTIFIED AS CONTAMINANTS

4.1.2.1 Soils and Aquifer Sediments

Some of the contaminants identified in soils near or at the Puchack Site, in particular the inorganics, are naturally occurring, or are likely to be present at elevated levels as a result of inputs from sources other than the Puchack Site under investigation. It is, therefore, important to be able to distinguish site-related contamination from local background levels of chemical constituents such as metals, that are present as geologic and atmospheric contributions to soils. Chemical data for similar soils from undisturbed areas of the New Jersey Coastal Plain can be used to assess the expected levels of metals derived from regional atmospheric deposition and geologic sources, and the mineralogy of local soils can indicate whether large concentrations of particular metals are likely. For example, sandy soils developed on two younger Cretaceous units (the Englishtown and Woodbury Formations that overlie the Magothy and overlying Pennsauken Formations) contain concentrations of chromium that typically are less than 5 milligrams per kilogram (mg/kg), but concentrations increase to 20 mg/kg or more in clays (Barringer et al. 1998). Coastal Plain glauconite, present in some soils and sediments of the study area, can contain from 130 to 1,000 mg/kg of chromium (Dooley 1998).

Although the upper limit of “background” chromium concentrations in soils developed on the sediments of the Magothy and Pennsauken Formations has not been firmly established, total chromium concentrations in excess of 20 mg/kg in sandy soils likely are the results of anthropogenic inputs, as, with the exception of glauconite, there are few weatherable minerals present in the sands that could contribute large concentrations of chromium either to soils or to aquifer sediments. The greater the clay/glauconite content of the soil or aquifer sediment, however, the larger the background concentration of total chromium is likely to be. Because hexavalent chromium [Cr (VI)] can adsorb to, and trivalent chromium [Cr (III)] can precipitate with, iron hydroxides (Davis and Olsen 1995), chromium concentrations also are likely to be higher in soils and sediments with high iron concentrations. Manganese dioxide, on the other hand, can oxidize Cr (III) (Palmer and Puls 1994), which could lead either to removal of mobile Cr (VI) from soils or adsorption to soil materials.

Concentrations of inorganic contaminants other than chromium in soils also may be enhanced as a result of their affinity for soil materials such as iron hydroxides, clays, or organic matter. For example, arsenic typically is associated with iron hydroxides and clays, and lead with organic matter. Organic matter in surficial soils sequesters lead deposited from the atmosphere. Some Coastal Plain soils that contain substantial amounts of iron hydroxides or clays may also contain substantial concentrations of arsenic that are naturally occurring (Barringer et al. 1998).

The issue of determining background levels of organic compounds such as benzene, toluene, ethylbenzene, and xylene (BTEX) and chlorinated solvents in soils and aquifer sediments does not commonly arise in investigations of organic contaminants because, with few exceptions, the compounds do not occur in natural settings. Nevertheless, concentrations of VOCs in urban air in New Jersey have been measured in the low (<0.5) parts per billion by volume (ppb/v) range (Pankow et al. 1998). Consequently, atmospherically deposited organic compounds can create ambient levels in soils of industrial areas that are detectable at low concentrations.

4.1.2.2 Groundwater

Naturally occurring total chromium and Cr (VI) concentrations in the aquifer system are typically low. The typical form of chromium that occurs naturally is chrome III, whereas, chrome VI typically does not occur naturally. Fusillo et al. (1984) report that, for most samples collected during 1923-83 from wells finished in the aquifer system, total chromium concentrations were 10 µg/L or less, and Cr (VI) concentrations typically were <1 µg/L. Samples from several area public supply wells, however, contained total chromium concentrations of 20-30 µg/L during 1980-82; the sample from Puchack 2 contained 40 µg/L of total chromium (Fusillo et al. 1984).

Analysis of water samples collected during 1999-2001 from wells outside the chromium plume areas indicates that chromium concentrations generally do not exceed 5 µg/L; although concentrations in a few samples were between 5 and 10 µg/L, concentrations were less than 5 µg/L in about one quarter of the samples collected outside the plumes. There are few minerals present in the aquifer sediments that would likely contribute large concentrations of chromium to groundwater.

Because the organic contaminants identified in groundwater underlying the Puchack Site typically do not occur naturally, background concentrations of most compounds should be undetectable in uncontaminated groundwater. Chloroform, however, can be formed by reaction of reactive chlorine species with organic matter in soils (Hoekstra et al. 1998). Some detections of chloroform in groundwater may be the result of such a reaction.

Concentrations of BTEX and chlorinated solvents in samples from most of the 519 wells finished in the Potomac-Raritan-Magothy aquifer system [presented in Fusillo et al. (1984)] were undetected. Detectable concentrations of VOCs such as TCE were reported for several areas with industrial and water-supply wells.

4.1.3 QUALITY ASSURANCE/QUALITY CONTROL

4.1.3.1 Soil and Aquifer Sediment Samples

QA/QC data for investigations into contaminants in soils and aquifer sediments are contained in data reports (Lockheed Martin 2000; CDM 2001a; CDM 2001b) for those investigations. Validation of results was done according to EPA Region II methods. During the earlier investigation (Lockheed Martin 2000), which is not part of this RI, 46 samples and one duplicate were collected for analysis of Cr (VI). Forty-five samples and one duplicate were collected for analysis of cadmium, total chromium, copper, iron, manganese, and zinc. Fifteen samples were

collected for analysis of VOCs. Results of laboratory QA/QC procedures, which are presented by Lockheed Martin (2000), were within QC limits. Agreement between results for field samples and duplicate samples was excellent, with relative percent differences (RPDs) of less than 10 percent.

QA/QC procedures and results for the subsequent soil boring investigation are reported by CDM (2001a). Sixty soil/sediment samples and five field duplicate samples were collected during the investigation of five industrial/commercial properties. Forty-eight aquifer sediment samples and six field duplicates were collected during the drilling of 44 monitoring wells. (A total of 64 wells were installed either individually or in clusters. Samples were collected from the well boring or from one boring in each cluster). RPDs between soil/sediment sample duplicate pairs generally were less than 20 percent, and ranged as high as 200 percent. The highest RPDs typically were for organics, including pesticides, PCBs, and VOCs; and were common for iron and zinc results; aluminum and magnesium results showed high variance for at least one pair of samples. Large RPDs for inorganic constituents in duplicate soil samples are common because variations in the mineral composition of duplicate samples typically can be large, resulting in high variance between results for common constituents such as iron and aluminum. Results of data validation indicated that the sample analyses generally met required QC criteria. Zinc, iron, and acetone were detected in some field, trip, and method blanks; results are qualified as required by EPA Region II data validation guidelines. The discussion of the quality of the data and the validated soil and aquifer sediment sample data are included in Appendix F.

4.1.3.2 Groundwater Samples

During 1999, 17 filtered environmental water samples from 13 wells, four duplicate samples, and 10 trip blanks and 4 field blanks were collected. A total of 115 environmental water samples, including 19 unfiltered and 7 filtered duplicates, were collected from 88 wells during 2000-2001, and 58 trip blanks and 17 field blanks also were collected. Two additional equipment blanks were collected in the USGS laboratory as a further check on cleaning procedures. In 1999, the samples were collected by the USGS, analyzed by the EPA (with the exception of chromium), and the data were validated following the EPA Region II guidelines and are presented in Appendix G. The chromium analyses were performed by Lancaster Laboratories. The results were checked and evaluated by the USGS for reasonableness. For example, an ion balance was performed by the USGS. Based on their analysis, the USGS considers the chromium data reliable although they have not undergone standard EPA data validation. The results of the sample analyses completed in 2000-2001 were validated by the EPA and CDM in accordance with EPA Region II guidelines and are presented in Appendix G.

Results for blanks collected in 1999 and 2000-2001 are presented in Appendix G. Barium, calcium, organic carbon, orthophosphate, nitrite, sulfate, and zinc were not detected in any blanks from the 2000-2001 sampling. Constituents detected below the applicable method required detection limits (MRDLs) in five or fewer blanks included cadmium, chloride, cobalt, iron, lead, magnesium, mercury, nitrite + nitrate, and potassium. Aluminum concentrations were detected at levels well below the MRDL of 100 µg/L in most of the blanks. Sodium concentrations were detected at <1.0 mg/L in most of the blanks; four blanks contained sodium at or between 1.0 and 1.61 mg/L. With a MRDL of 2 µg/L, estimated detections of total chromium were <1 µg/L in most blanks; three blanks contained total chromium estimated at or

between 1.0 and 1.6 µg/L. The detection of low levels of chromium in most equipment blanks indicates that concentrations of chromium determined to be at background levels in groundwater may be slightly higher, in some cases, than they actually are; nevertheless, the large concentrations measured in chromium-contaminated groundwater samples are unaffected by the small amounts of chromium measured in the blank samples.

RPDs for inorganic constituents in pairs of duplicate samples from 1999 typically were <5 percent; the RPD for the only detection in the VOC duplicate pair was 13 percent. RPDs for inorganic constituents in pairs of duplicate samples from 2000-2001, collected as duplicates, typically were <10 percent and most were <5 percent. Duplicate sample data with RPD calculations are presented in Appendix G.

For environmental samples, analytical results for high (>1,000 µg/L) concentrations of Cr (VI) typically are higher than the results for total chromium. For mid-range concentrations (100-1,000 µg/L), results for hexavalent and total chromium tend to be similar. The discrepancy between high values for these two analytes indicates that precision of measurement for Cr (VI) declines as the concentration increases. Therefore, for the purposes of this study, high total chromium concentrations are considered the more reliable measure of the amount of chromium present.

4.2 EXTENT AND NATURE OF CONTAMINATION IN SOILS FROM FIVE INDUSTRIAL/COMMERCIAL PROPERTIES

Based on the results of previous investigations in the vicinity of the Puchack Well Field Superfund Site, as discussed in Subsection 1.3, five commercial and industrial properties have been identified as potential sources of groundwater contamination at the Puchack Site: Advance Process Supply (APS), Mercon, King Arthur, SGL Modern Hard Chrome Service (SGL Chrome), and Supertire (Figure 4-1). These previous investigations, which were performed by NJDEP, include Environmental Strategies Corporation (1990), Enviro-Sciences, Inc. (1990), Geotech Environmental, Inc. (1990), John G. Reutter Associates (1982), Rhodes Engineering (1990), and Stablex-Reutter Inc. (1984).

In 1999, the EPA completed soil borings and soil/aquifer sediment sampling at APS and Mercon. The borings were installed using direct push technology, penetrating soil horizons and geologic sediments to depths up to 19 feet bgs.

As part of the OU1 field investigations completed in 2000, CDM, in cooperation with the EPA ERT, completed soil borings at King Arthur, Mercon, SGL, and Supertire (Figure 4-1). Samples were collected with a split-spoon sampler through a hollow-stem auger to depths of 100 feet bgs.

Results of the soil borings collected at these five commercial and industrial properties reveal that there are differences in the composition of soils and sediments and concentrations of various metals, including chromium, between these five sites. The distribution of chromium concentrations with depth at the five properties is of interest insofar as pathways for chromium to enter the aquifer system may be discerned. Additionally, relations between chromium and soil constituents such as iron may be illustrative of chemical interactions between the soil and the contaminant. Aquifer sediment sample results from the screened interval of monitoring wells

can provide information on reactions between chromium and constituents such as iron and manganese that may occur in the aquifers.

Given the prevalence of acetone as a laboratory contaminant, reported occurrences of acetone in the samples will not be discussed further.

A more detailed analysis of the sample results at each property is presented below.

4.2.1 ADVANCE PROCESS SUPPLY PROPERTY

4.2.1.1 Inorganic Contamination

Cores from four soil borings (SB-01, -02, -03, and -04) were collected at depths up to 19 feet bgs, which is above the water table (Lockheed Martin 2000). Hexavalent chromium was only detected, at 4.4 mg/kg, in one sample of the 16 samples collected. This sample was collected from 17 feet bgs in soil boring SB-01. Total chromium ranged from 4.8 to 55 mg/kg (median = 27.5 mg/kg) (Figure 4-2), as compared to SSL-1DAF of 2 mg/kg and NRDCSCC of 20 mg/kg.

The concentrations in most of these relatively shallow sediment samples appear to be above background levels by factors of 2 to 5. No consistent trends in concentration with depth were apparent, however, and it is not known whether the elevated chromium concentrations continue throughout the unsaturated zone to the water table. Given only a single detection of Cr (VI), it is likely that virtually all of the chromium present in soil/sediment samples from this site is in the reduced, trivalent form. In general, higher total chromium concentrations were associated with higher iron concentrations, which ranged from 1,500 to 86,000 mg/kg (median = 26,500 mg/kg) (Figure 4-3), a relation observed in soil samples from other locations in the study area. No relation between manganese (range 2.5 to 3,300 mg/kg) and total chromium concentrations at the APS property was apparent.

4.2.1.2 Organic Contamination

Few organic contaminants were detected. BTEX compounds [ethylbenzene, toluene, p-xylene, and o-xylene], 4-methyl-2-pentanone (or MIBK) and compounds that are associated with dyes (1,2,4-trimethylbenzene, n-propylbenzene, and naphthalene) were detected (Appendix F). However, none of these compounds were detected in concentrations above the NRDCSCCs or IGWSCCs.

4.2.2 KING ARTHUR PROPERTY

4.2.2.1 Inorganic Contamination

Results of analysis of samples from three borings (ERTSB11, 12 and 13; Figure 4-4) at the King Arthur property southwest of the Puchack well field indicate that Cr (VI) concentrations in 10 samples ranged from <1 to 16 mg/kg (median = 1 mg/kg), with the samples from boring ERTSB13 containing the highest concentrations (CDM 2001a and 2001b). Total chromium concentrations ranged from 1.2 mg/kg to 43.8 mg/kg (median = 8.9). The highest concentrations were in samples collected between ground surface and 10 feet bgs; the deeper samples from all

three borings contained total chromium concentrations at what appear to be background levels (<10 mg/kg). Only boring ERTSB11 penetrated below the water table to a depth of 100 feet bgs.

Samples ERTSB11-A, ERTSB12-B, ERTSB13-A, and ERTSB13-B contained total chromium concentrations of 39.9, 26.4, 34, and 43.8 mg/kg, respectively, whereas Cr (VI) concentrations were 1 mg/kg, 1 mg/kg, 8 mg/kg, and 16 mg/kg, respectively. Thus, virtually all the chromium in the first two samples was Cr (III), but a significant proportion of the chromium in the latter two samples was Cr (VI). Therefore, assuming any inputs of chromium to soils on this property were in the hexavalent form, the degree to which soil materials have reduced Cr (VI) has varied, spatially. This variation may be the result of excavation, subsurface releases of chromium, and backfilling with non-native soils.

Overall, the highest concentrations of total chromium typically were associated with higher concentrations of iron and (sometimes) manganese in the samples from the first 10 feet of the three cores. Iron concentrations ranged from 644 mg/kg to 100,000 mg/kg (median = 8,925 mg/kg) in soil and aquifer sediment samples; concentrations typically, although not always, decreased with depth. The association of the higher Cr (VI) concentrations with high iron concentrations in the first ten feet of boring ERTSB13 probably indicates adsorption of Cr (VI) to iron hydroxides in B-horizon soils.

Given the co-occurrence of concentrations of chromium, arsenic, selenium, and thallium that are higher than most soil samples from the area, there is some metal/metalloid contamination of the soils at the King Arthur property. Arsenic concentrations in samples ERTSB11-A, ERTSB12-B, ERTSB13-A and B were 25.1, 30.5, 19.2 and 27.2 mg/kg, respectively. These concentrations, which appear to be above background levels, may be traceable to use of arsenical pesticides in the past, as the area included farms and orchards through the 1950s (Enviro-Sciences, Inc. 1990). Sample ERTSB11-A also contained thallium at a concentration (30.7 mg/kg) exceeding the NRDCSCC (Table 4-3). The source of the thallium is unknown, as is the source of selenium; this latter constituent was found in concentrations that exceed the SSL-1DAF in samples B and C from boring ERTSB12 (CDM 2001b) (Table 4-4).

4.2.2.2 Organic Contamination

VOCs were not detected in soil and sediment samples from three borings installed at the King Arthur property, with the exception of low levels of methylene chloride in three samples and low levels of toluene in two others (CDM 2001a). Given the ubiquity of methylene chloride as a laboratory contaminant, the detections of this compound may not indicate an environmental contaminant in these soils.

Aroclor 1248 was detected in the samples from ERTSB-12B and 12C at concentrations of 1,400 and 240 mg/kg, respectively. Neither concentration exceeded the NRDCSCC nor IGWSCC for PCBs.

4.2.3 MERCON PROPERTY

4.2.3.1 Inorganic Contamination

Results of analysis of samples from nine borings down to 18 feet bgs surrounding the storm water retention basin (lagoon) at the Mercon property (SB-05 through SB-13; Figure 4-5), and four subsequent borings (ERTSB01 through 04) in the same area down to 57 feet bgs indicate that total chromium concentrations in soils and sediments ranged from 0.69 to 20 mg/kg. Chromium concentrations tended to decrease with depth, (Lockheed Martin 2000; CDM 2001a, CDM 2001b), although concentrations >10 mg/kg typically occurred in shallow samples down to 4 feet bgs, one sample from 12 feet bgs (SB-05) contained 20 mg/kg of total chromium. There is currently no evidence of elevated chromium concentrations in soils or in sediments near the water table, however. Hexavalent chromium concentrations ranged from <1 to 3 mg/kg. Therefore, most of the chromium present appears to be in the reduced, trivalent form.

Iron concentrations ranged from 260 to 60,000 mg/kg (median = 4,600 mg/kg). The highest iron concentrations at each ERT boring location were found in the upper two feet of soil, probably representing the upper B-horizon soils, or part of the “zone of accumulation.” The upper intervals in the “SB” soil borings ranged from 3 to 5 feet bgs; in these, iron concentrations were substantially higher than in deeper intervals. In general, total chromium concentrations tended to increase as iron concentrations increased.

Manganese concentrations ranged from 1.2 to 620 mg/kg (median = 12 mg/kg). Low (<4 mg/kg) concentrations of total chromium were associated with both very high and very low concentrations of manganese; no significant relations between concentrations of the two constituents could be discerned. Concentrations of constituents such as arsenic, beryllium, lead, selenium, and thallium generally were either low or undetected, although arsenic and chromium exceeded SSL-1DAF criteria in one sample, and selenium in another.

4.2.3.2 Organic Contamination

VOCs typically were not detected in soil and sediment samples from 13 borings at the Mercon property, with the exception of low levels of 1,1,1-TCA in samples from two borings (Lockheed Martin 2000; CDM 2001a). Concentrations of 1,1,1-TCA ranged from 7 to 16 µg/kg, and were detected as deep as 57 feet bgs, indicating that this compound can be mobile in soils and (or) sediments. None of the concentrations exceeded the NRDCSCC.

4.2.4 SGL CHROME PROPERTY

4.2.4.1 Inorganic Contamination

Results of analysis of samples from four borings (ERTSB05 through 08; Figure 4-6) at the SGL Chrome property indicate that total chromium concentrations ranged from 7.6 to 1,290 mg/kg (median = 25.3 mg/kg) (CDM 2001a). Samples from ERTSB07 and ERTSB08 contained the highest (> 70 mg/kg) concentrations of total chromium in 7 of 10 samples. Total chromium concentrations at these two boring locations tended to decrease with depth, although substantial concentrations (130 and 101 mg/kg) were found in samples from depth intervals at 45-47 and 52-54 feet bgs respectively, at the water table (Figure 4-7).

Figure 4-7 compares the total chromium concentrations to Cr (VI) concentrations. In most cases, the samples with high concentrations of total chromium contained low or undetectable

concentrations of Cr (VI), indicating that a substantial amount of Cr (VI) had probably been reduced by materials in the soil or sediments. The capacity of the soils to reduce Cr (VI) apparently is larger at shallow depths, as indicated by sample ERTSB08-A (0-2 feet bgs) which had a total chromium concentration of 1,290 mg/kg but contained no detectable Cr (VI), and thus did not exceed the NRDCSCC for Cr (VI) via the inhalation pathway (Table 4-3). Only the sample from 10-12 feet bgs (ERTSB07-B) contained 87.8 mg/kg total chromium and 110 mg/kg Cr (VI), indicating that reduction had not occurred and most or all of the chromium present could be considered to be in the oxidized, Cr (VI), state.

In general, the higher total chromium concentrations were in samples with high iron concentrations. Iron concentrations ranged from 177 to 49,400 mg/kg (median = 4,970 mg/kg); iron concentrations were higher in samples from the second intervals (6 to 17 feet bgs) than in surface soils in three of the four borings: ERTSB05, ERTSB07, and ERTSB08 (CDM 2001a), probably reflecting leaching and accumulation of iron during weathering processes. The presence of higher Cr (VI) concentrations in the second intervals may reflect adsorption of Cr (VI) to iron hydroxides in the soils or sediments at those depths.

Given that there were waste pits on the property and that the topography is not flat, chromium inputs may have varied aurally, and runoff may have played a role in the distribution of chromium at the land surface. The limited number of soil borings do not give a complete picture of what that distribution may be. The relations between total and Cr (VI) with depth in existing borings indicate (1) that Cr (VI) has been reduced near the soil surface (probably mostly by organic matter), (2) that some Cr (VI) has adsorbed to sediments at greater depths, and, (3) given the large concentrations of Cr (VI) in the groundwater beneath the SGL Modern Chrome property, most of the Cr (VI) introduced at the SGL Modern Chrome property probably has passed through the soils unchanged.

Surficial soil samples at the SGL Chrome property also contained inorganic contaminants other than chromium. Lead, thallium, and arsenic were detected sporadically at concentrations above the NRDCSCCs and background levels. Antimony, cadmium, mercury, nickel, and selenium exceeded SSL-1DAF criteria in one or more samples (Table 4-4). Although the occurrences are sporadic, metallic contaminants other than chromium are present in the soils of the SGL Chrome property.

4.2.4.2 Organic Contamination

1,1,1-TCA was detected in one or more samples from all four borings at the SGL Chrome property. Detected concentrations were low, ranging from 2 to 22 µg/kg. Although most detected PCE concentrations were low, a concentration of 65 µg/kg was reported for the sample from 25-27 feet bgs at boring ERTSB06, and a concentration of 240 µg/kg was reported for the sample from the 15 to 17 feet bgs interval at boring ERTSB08 (Figure 4-8). A TCE concentration of 92 µg/kg was reported for the same interval. Metal shavings and debris were present in the sediment (1-12 feet and 10-12 feet bgs) above this interval, and metal fragments were present at 15-17 feet bgs (CDM 2001b), indicating discarded wastes that may explain the isolated instance of these organic contaminants at 15 feet bgs. Relatively low concentrations of 1, 4-dichlorobenzene, ethylbenzene, isopropylbenzene, and xylenes (<20 µg/kg) also were present in this interval.

Ethylbenzene, isopropylbenzene, and xylenes were detected in the surface soils (0-2 feet bgs), the latter at 110 µg/kg. Consequently, some of the organic contaminants appear to have moved from the soil surface to deeper levels. TCE at a concentration of 97 µg/kg also was found in a sample from the interval 57 to 59 feet bgs at nearby boring location ERTSB07 (CDM 2001a); this interval is below the water table and is within a clay layer. None of the concentrations measured exceeded NRDCSCCs or IGWSCCs. Concentrations of Aroclor 1254 were 380 and 570 µg/kg, respectively, in samples from ERTSB08A (0-2 feet bgs) and 9B (14-16 feet bgs); neither concentration exceeded the NRDCSCC or IGWSCC for PCBs.

4.2.5 SUPERTIRE PROPERTY

4.2.5.1 Inorganic Contamination

The Supertire property is located outside and downgradient of the current chromium plume. Analytical results from the samples collected from five borings (ERTSB09 and 10, ERTSB14 through 16; Figure 4-9) at the Supertire property south-southeast of the Puchack well field indicate that total chromium concentrations in soils at the Supertire property ranged from 1.2 to 185 mg/kg (median = 2.8 mg/kg) (CDM 2001a). The highest total chromium concentration of 185 mg/kg occurred in soil from 0-2 feet bgs (ERTSB14-A) and is an extreme outlier; such a concentration in a surficial soil sample probably represents anthropogenic inputs of chromium to the soil at this property. Hexavalent chromium was not detected in the majority of samples from this site. When detected, concentrations were ≤ 5 mg/kg, and thus did not exceed the NRDCSCC for the inhalation pathway. Consequently, nearly all of the chromium present in samples from this property is in the reduced trivalent form.

The iron concentration (9,410 mg/kg) for sample ERTSB14-A is high relative to iron concentrations in most other samples from the Supertire property. Overall, iron concentrations in samples from the Supertire property ranged from 315 to 22,200 mg/kg (median = 1,770 mg/kg). The concentration at 22,200 mg/kg was an extreme outlier, occurring in the 0-2 feet bgs interval of boring ERTSB10. Samples from the same interval (representing B-horizon soils) at the other boring locations contained iron at concentrations $<10,000$ mg/kg. In general, iron concentrations decreased with depth at all boring locations at this site but iron concentrations in samples from this property, for a given sampling interval, tend to be lower than those from the other properties sampled. This may affect the capacity of the soil to reduce or sequester chromium.

Manganese concentrations generally were low, ranging from 1.1 to 168 mg/kg (median = 3.5 mg/kg). The highest total chromium concentration (185 mg/kg) was in the sample (ERTSB14-A) with the highest manganese concentration. The Cr (VI) concentration in this sample was reported as <25 mg/kg; consequently, it is difficult to assess whether any Cr (VI) is present, or what the potential for oxidation of Cr (III) by manganese oxides might be.

Other metals detected in samples from the borings at the Supertire property included arsenic at 19.6 mg/kg in sample ERTSB10-A (just below the NRDCSCC) and lead at 73.2 mg/kg in sample ERTSB10-A, and 137 mg/kg in ERTSB14-A. These lead concentrations are in the range expected for soils that received lead from atmospheric deposition, and the geologist's soil logs indicate that organic matter that would sequester lead probably is present. It is currently not possible to determine what the source of arsenic might be, but past use of arsenical pesticides

during agricultural activities is a possibility. The thallium concentration in ERTSB10-A was 8.3 mg/kg (exceeding the NRDCSCC; Table 4-3), indicating some contamination from metals is present in surficial soils at this property.

4.2.5.2 Organic Contamination

Soil gas samples were collected using direct-push technology at nine locations on the Supertire property, at depths of about 5 to 6 feet bgs (Lockheed Martin 2000). Analysis of the gas samples indicates that 1,1-DCE, 1,1,1-TCA, and PCE were detected; the first two compounds at concentrations that exceeded 100,000 ppb/v at one location (Figure 4-9). Analysis of samples from soil boring ERTSB09 on the same property indicated that concentrations of 1,1,1-TCA in soils and aquifer sediments increased with depth from 69 µg/kg at the surface through 33,000 to 440,000 µg/kg at 22-24 feet bgs, and were 11,000 µg/kg at the interval 50 to 52 feet bgs (Figure 4-10). 1,1-DCE also was detected in the soils and sediments, but at substantially lower concentrations. The highest concentration of 1,1,1-TCA (444,000 µg/kg) did not exceed the NRDCSCC but exceeded the IGWSCC. The compound may have pooled as a dense non-aqueous liquid (DNAPL) at the interval 22 to 24 feet bgs because a stiff silt is present at about 25 feet bgs (CDM 2001a).

4.3 EXTENT AND NATURE OF CONTAMINATION IN AQUIFER SEDIMENTS

4.3.1 INORGANIC CONTAMINATION

Samples of aquifer sediments were collected during the drilling of monitoring wells in 1997 (shown on Plate 1) and again during 2000-2001 (Figure 2-1). The aquifer sediments sampled for chemical analysis during monitoring well installation were collected, with few exceptions, only from the interval where the well screen would be located. Therefore, these sediments are representative of the material most likely to be in contact with water withdrawn from each well, but the chemical characteristics of sediments above or below the well screen generally are not known.

In 1997, as part of the NJDEP investigation, the USGS collected aquifer sediment samples at the approximate depths where well screens would be placed during the installation of 10 monitoring-well clusters. Hexavalent chromium was detected in six of the 30 sediment samples; detections ranged from 0.45 to 2.4 mg/kg (Table 4-5). Total chromium concentrations for all 30 of the same samples ranged from 1.28 to 12.2 mg/kg, with a median of 3.07 mg/kg. The two highest total chromium values (12.2 and 11.8 mg/kg) were in sediments from intervals at or above where high concentrations of Cr (VI) (600 µg/L and >1,500 µg/L, respectively) were present in groundwater. Those two sediment samples also contained the highest Cr (VI) concentrations (0.93 and 2.4 mg/kg, respectively). Hexavalent chromium concentrations in the other sediment samples were either undetectable or less than 0.6 mg/kg; therefore, most of the chromium present in the sediments was present in the trivalent form.

As part of the present OU1 RI effort, forty-eight sediment samples were collected in 2000-2001 at 44 monitoring well cluster locations (CDM 2001a). Samples were collected at two different depths (well screen and above) at four of the locations, the rest were only from the intended depths of the well screens. Total chromium concentrations ranged from 1.5 to 26.3 mg/kg; the

median value was about 5 mg/kg both with and without duplicate samples included. The highest concentration, 26.3 mg/kg from the P MW-11I boring, is an outlier; it is not known whether this sample represents an unusually high naturally occurring concentration, or is contaminated in some way. Total chromium concentrations in all other samples were <14 mg/kg.

Hexavalent chromium detections ranged from 0.5 to 5 mg/kg in 33 samples. Hexavalent chromium data were rejected during data validation for the sample from the boring at P MW-11I, which is the sample that contained the highest concentration of total chromium. For those samples in which Cr (VI) was detected, the ratio of Cr (VI) to total chromium tended to decrease as the concentration of total chromium increased (Figure 4-11). This relation indicates that, as concentrations of chromium in the aquifer sediments increase, slightly more of the chromium is present as reduced Cr (III). Therefore, Cr (VI) appears to be reduced to Cr (III) to a limited extent, probably by materials such as ferrous iron-bearing minerals or organic matter present in the aquifer sediments.

Iron concentrations in aquifer sediments collected during well drilling generally were low, relative to those in most soil and sediment samples collected from the commercial and industrial areas in the vicinity of the Puchack well field. Concentrations in the aquifer sediments ranged from 190 to 7,100 mg/kg, and commonly were highly variable in duplicate samples from the same interval [relative percent differences ranged from about 3.5 to 142 (CDM 2001a)], indicating that the amount of particular minerals in a given sample can have a large effect on the concentration of iron measured.

Manganese concentrations in the aquifer sediment samples ranged from 1.8 to 107 mg/kg; the latter is an extreme outlier, as nearly all concentrations were < 20 mg/kg.

Concentrations of other metals generally were undetected or low in samples of aquifer sediments; arsenic, beryllium, cadmium, lead, and thallium commonly were less than 2 mg/kg when detected. Mercury typically was undetected at 0.06 mg/kg, but was detected at 0.13 and 0.32 mg/kg in sediment samples from CC MW1DSB-A and CC MW2DSB-A, respectively. Both organic-rich clays and lignite could be sources of the mercury in the sediments.

4.3.2 ORGANIC CONTAMINATION

SVOCs, PCBs, and pesticides were rarely detected in samples of aquifer sediments collected during drilling of monitoring wells. Bis (2-ethylhexyl) phthalate was detected at a concentration of 1,700 µg/kg in the sample from the borehole for P MW-16D, and at 230 µg/kg from the borehole for P MW-16I. A few other detections of this compound were at concentrations less than 150 µg/kg. Aroclor 1248 was detected at 2,500 µg/kg in the sample collected at 138 feet bgs from the borehole for CC MW-4I (CDM 2001a). Figure 2-1 shows the boring locations. P MW-16I and P MW-16D are located in an empty lot at south of the intersection of River Road and DeRousse Avenue. Monitoring well CC MW-4I is located in front of the elementary school south of Puchack Well field (Figure 2-1).

Concentrations of VOCs generally were not detected in aquifer sediments collected during monitoring well installation. Compounds detected included, in order of frequency, toluene, 1,1,1-TCA, ethylbenzene, PCE, TCE, 1,4-dichlorobenzene, and chloroform. Detections typically

were <10 µg/kg, and most detections were <5 µg/kg. Total xylenes were the exception, with concentrations in 11 samples from 10 boreholes ranging from 7 to 52 µg/kg; the boreholes were for wells CC MW-2D, P MW-13M, 13I, 19M, 21S, 25D, 26M, 26I, 34M, and 34I. The sample from the borehole for P MW-21S, at 50-52 feet bgs, also contained 110 µg/kg of TCE (CDM 2001a).

4.4 EXTENT AND NATURE OF CONTAMINATION IN GROUNDWATER

The areal and vertical distributions of inorganic contaminants (principally chromium) and organic contaminants (including, but not limited to, TCE) in the vicinity of the Puchack well field are different. Much of the difference in distribution probably is related to differences in locations of known or potential sources. Nevertheless, some of the differences in distribution may be the result of chemical changes that differentially affect the persistence and (or) the rate of transport of the various contaminants.

4.4.1 CHROMIUM CONTAMINATION

The principal inorganic contaminant, chromium, to date has been measured in concentrations that are above expected background concentrations or that exceed the MCL in three of the four water-bearing units in the study area. Figure 4-12 depicts the sample locations and summarizes selected inorganic contaminant results where those contaminants exceeded their respective MCL.

Both hexavalent and total chromium were measured in all samples; because six Cr (VI) values were rejected, not all pairs of values can be compared. Hexavalent chromium concentrations ranged from <10 to 9,420 µg/L (a duplicate sample contained 12,600 µg/L). Total chromium concentrations ranged from 0.23 to 8,010 µg/L. Total chromium values should reflect the sum of individual chromium species; however, the highest Cr (VI) values were substantially higher than their corresponding total chromium values. The precision of measurement of Cr (VI) at high concentrations appears to decrease with increase in concentration. Consequently, in most cases, determination of Cr (III) concentrations by difference was not possible, because concentrations of the individual species [Cr (VI)] were greater than the concentrations of the sum of species (total chromium). In general, it appears that most, if not all, of the chromium measured in groundwater samples is in the oxidized, hexavalent form.

Additional samples from 24 wells were filtered in the field in 2000-2001; a comparison of the analytical results for filtered and unfiltered samples from these wells indicates that, in general, concentrations of total chromium were similar for both types of samples within the expected analytical error. For samples with low concentrations of total chromium, the unfiltered sample concentrations tended to be slightly higher than the filtered concentrations. Nevertheless, the data indicate that nearly all of the total chromium measured either was in a truly dissolved form, or adsorbed to particles small enough to pass a 0.45 micron (µm) pore-size filter.

4.4.1.1 Upper Aquifer

There is no monitoring well installed in the Upper aquifer within the Puchack chromium plume area because the Upper aquifer is unsaturated throughout most of the area of concern. One off-

site well (GSM MW-1) finished in the Upper aquifer was sampled during 1999-2001. The Cr (VI) concentration in the sample from well GSM MW-1 was <10 µg/L. The total chromium concentration was 4.2 µg/L. Because the MRDL for Cr (VI) is higher than that for total chromium, it is not possible to determine from these data whether the chromium present in this sample is Cr (VI) and/or Cr (III). The DO concentration in the sample was 7.35 mg/L, and the total iron concentration was relatively low at 232 µg/L. Given the higher solubility of Cr (VI) species than Cr (III) species and the indicators of an oxic geochemical environment of the Upper aquifer in the area sampled (high DO and low iron concentrations), it is plausible that the chromium is present in the hexavalent state. The concentration of total chromium measured probably is at or near background levels.

4.4.1.2 Middle Aquifer

Twenty-six wells finished in the Middle aquifer, nine in layer A-2a, and 17 in layer A-2b, were sampled in 1999 and during 2000-2001. Total chromium concentrations in samples from two wells exceeded 100 µg/L; these were from wells Landfill-4 (a filtered sample), an off-site well, and P MW-1S (an unfiltered sample) in layer A-2b. Figure 4-13 depicts the sample results. Samples collected previously (1997-98; Walker and Jacobsen, in press) indicated high concentrations of chromium in water tapped by these two wells.

The total chromium concentration in the sample from Landfill-4, an off-site well, was 290 µg/L; the Cr (VI) concentration was 289 µg/L. These data indicate that all of the chromium present in water tapped by well Landfill-4 is Cr (VI). The total chromium concentration in the sample from P MW-1S, which is located at the SGL Chrome property, was 8,010 µg/L, and the Cr (VI) concentration was 9,420 µg/L. As with other water samples collected during this study with high chromium concentrations, the hexavalent value is larger than the total value, indicating a decrease in analytical precision for Cr (VI) as concentrations increase. On the basis of the similar hexavalent and total chromium values, all of the chromium present in the sample from P MW-1S is Cr (VI).

Well Landfill-4 is located adjacent to the Pennsauken landfill, nearly 1.5 miles northeast of well P MW-1S, which is located on SGL property. Figure 4-13 depicts the locations of the two monitoring wells, Pennsauken landfill, and SGL. Water samples from Middle aquifer wells between Landfill-4 and P MW-1S contain chromium at background levels (< 5 µg/L), and, based on groundwater flowpaths, there is no connection between the two areas with chromium-contaminated groundwater. As indicated by the data, there appear to be separate sources of chromium to these two areas. The P MW-26 monitoring well cluster is located downgradient from monitoring well P MW-1S but water sample results from P MW-26M show low levels of Cr (VI). Monitoring wells P MW-1S and P MW-26M are both completed in the Middle Aquifer. The concentration drops between P MW-1S and P MW-26M because groundwater contaminated with chromium is moving downward before it reaches P MW-26M. See Section 3.5.2.1 for a full discussion of the hydrostratigraphy of the site. The site conceptual model, presented in Section 5.1.3.1 presents an analysis of the flow system that explains the observed pattern of chromium contamination in groundwater.

Of the rest of the Middle aquifer wells (24), eight are finished in the upper water-bearing zone (A-2a) and 16 are finished in the lower water-bearing zone (A-2b). Total chromium

concentrations detected in water from this group of wells were at background levels (0.23-3.8 µg/L). Because the Cr (VI) concentrations typically were reported as <10 µg/L, no direct assessment of the oxidation state of the chromium can be made.

DO concentrations in samples from 22 of these wells generally were moderate to high (3.55-10.04 mg/L) and iron concentrations generally were low (12.9-332 µg/L), so conditions in most of this part of the aquifer probably are oxic. Samples from three wells in the western part of the study area, P MW-8M, 10M and 16M, however, contained low DO concentrations (0.14, 0.36, and 1.81 mg/L, respectively) and high iron concentrations (61,300 and 11,700, and 9,100 µg/L, respectively). Two, P MW-10M and 16M, contain substantial amounts of VOCs that are probably being degraded, hence the low DO concentrations. Farther to the east, well CC MW-1B, surrounded by wells tapping water with low iron concentrations, yielded water with 3,550 µg/L of iron; the DO concentration in this sample was 4.83 mg/L, however. The data indicate that geochemical environments, including redox conditions, can vary substantially over relatively short distances in the Middle aquifer, which is confined to varying extents over much of the sampled area by the overlying layer C-1.

Because the current extent of the groundwater contamination at monitoring well P MW-1S is defined by data from only one well, the extent of the contamination in the Middle aquifer still is not clearly delineated. In particular, there are few wells that tap Middle aquifer water above, or slightly upgradient of, the core of the chromium plume in the Intermediate Sand (see discussion in next section). Consequently, transport of chromium to the plume in the Intermediate Sand from an as yet unknown source above or slightly upgradient of the plume core cannot be ruled out.

4.4.1.3 Intermediate Sand

Many of the wells yielding chromium-contaminated water in the study area are finished in the Intermediate Sand, the local sand unit (C-2AI) within the Middle/Lower confining unit (C-2a, C-2b) identified during a previous study (Walker and Jacobsen, in press). In the area where chromium-contaminated water is present in the Intermediate Sand, the silt and clay layers of the Middle/Lower confining unit are discontinuous; thus, the confining unit is ineffective in preventing the movement of contaminated water in the Middle aquifer to the Intermediate Sand.

Total chromium concentrations in water from the Intermediate Sand ranged from 0.71 to 6,310 µg/L. Figure 4-14 depicts the sample results. Nine of 30 wells finished in the Intermediate Sand yielded water with chromium concentrations that equaled or exceeded 100 µg/L (two filtered samples, seven unfiltered samples), and, of these, five (CC MW-1A, CC MW-2A, P MW-5I, P MW-14, P MW-25I) yielded water containing chromium concentrations in excess of 1,000 µg/L. The spatial extent of the chromium plume, defined by a 100-µg/L contour (the MCL for chromium), covers an area that is about 0.3 square miles, the long axis of which trends approximately east-west with a small separate area to the north, near the Puchack well field (Figure 4-14). The separate area is probably a remnant of an earlier plume configuration that resulted from pumping at the Puchack well field. The highest concentrations of chromium are at the eastern portions of the plume. The samples from wells CC MW-4I, P MW-23M, P MW-26I, and P MW-27I on the northwest border of the plume, contained 23.2, 50.9, 22.1, and 47.7 µg/L of chromium, respectively, concentrations well above background levels, but not exceeding the

MCL. These may represent residual contamination resulting from a shift in the plume's position toward the southeast in response to regional groundwater flow after pumping at the Puchack well field ceased.

The Cr (VI) concentrations in most cases were similar to those for total chromium where concentrations were low, and were higher than total chromium concentrations where concentrations were high. In general, most of the chromium present appeared to be in the form of Cr (VI); one exception was wells P MW-17I, the sample from which contained 100 µg/L of total chromium, and only 14 µg/L of Cr (VI). The Cr (VI) result is puzzling, insofar as the pH of the sample (5.08) is not as low as some other samples from the chromium plumes where dissolved Cr (III) species such as CrOH^{2+} could be expected. The difference between total and Cr (VI) values for samples from the plumes with pHs below 5.0 are negligible, however, and there is no evidence of dissolved Cr (III) species. As the samples from P MW-17I had low turbidity (0.71 NTU), it is unlikely that 86 µg/L (total chromium minus Cr (VI)) of the total chromium in these samples could be accounted for as Cr (III) adsorbed to particles.

4.4.1.4 Lower Aquifer

Forty-three wells finished in the Lower aquifer (layers A-3a, A-3b, and A-3c) below the Intermediate Sand were sampled during 1999-2001. Figure 4-15 depicts the sample results. Water samples from most of these wells contained total chromium concentrations at or near background levels; nine wells (CC MW-2D, P MW-5D, P MW-6D, P MW-14I, P MW-14Bethel-I, P MW-15I, P MW-22D, P MW-23I, and P MW-25D), however, yielded water with chromium concentrations that ranged from 129 to 4,810 µg/L. Samples from two other wells (P MW-14D and P MW-15D) in the same area contained chromium concentrations above background levels (9.8 and 62.1 µg/L, respectively), assuming that background concentrations are <5 µg/L. The Lower aquifer wells tapping water with chromium concentrations that exceed the MCL define a plume that covers an area about as large as that covered by the plume in the Intermediate Sand. The plume in the Lower aquifer has a different orientation than that in the Intermediate Sand, however, as the long axis trends northeast-southwest (Figure 4-15). The distribution and range of chromium concentrations in the plume differs among layers in the Lower aquifer, with the highest chromium concentrations in the upper layer A-3a.

Hexavalent chromium concentrations generally were similar to, although sometimes larger than, total chromium concentrations in samples from wells in the Lower aquifer. Hexavalent chromium concentrations were substantially less than total chromium concentrations in samples from only two wells (P MW-6D and P MW-25D). Consequently, the data indicate that most of the chromium in the Lower aquifer plume is present as Cr (VI).

4.4.2 ORGANIC CONTAMINANTS

A variety of organic contaminants are represented in all four water-bearing units in the study area. The types of compounds present typically belonged to two general groups—chlorinated two-carbon compounds (alkanes and alkanes), and petroleum hydrocarbons, principally aromatics (compounds that incorporate a benzene ring). Table 4-6 lists selected compounds that were detected at higher frequency. Of these, TCE is virtually ubiquitous, PCE nearly so, and their degradation products are common; other types of chlorinated solvents are less common, and

the BTEX are limited in extent. Figure 4-16 depicted selected VOC sample results that exceed MCLs for related compounds.

While VOCs hot spots were encountered within the boundaries of the Puchack Site chromium plume, coherent VOC plumes have not been identified. Figure 4-17 shows the location of VOC hot spots encountered during the OU1 RI investigation. Also identified are the known contaminated sites close to or within the OU1 boundary which have been identified by the NJDEP (2002b). Within the vicinity of the Puchack Site the VOC hot spots that were encountered during the OU1 RI have commingled with the chromium plume. VOC hot spots outside of the Puchack chromium plume are not included in the scope of the Puchack Site OU1 RI. The VOCs appear to have been released from several source areas. This section summarizes the findings of the OU1 RI and presents the nature and extent of contamination in groundwater.

Because concentrations of a few chlorinated compounds were sufficiently high in some samples as to require dilution of the sample for analysis, detection limits for associated compounds were higher, and thus detections of low levels of these associated compounds were not possible under those circumstances.

4.4.2.1 Upper Aquifer

There are no monitoring wells screened in the Upper aquifer within the Puchack Site. Only one off-site well sampled during 1999-2001 is finished in the Upper aquifer. TCE was present in the sample from well GSM MW-1, an off-site well, at a concentration of 990 µg/L. Concentrations of cis-1,2-DCE and 1,1,1-TCA were 450 and 55 µg/L, respectively. The well is located to the north of Route 90 and east of Union Avenue on the Garden State Motors, Inc. property. Figure 4-16 depicts the location of well GSM MW-1.

4.4.2.2 Middle Aquifer

Several VOC concentrations in sixteen monitoring wells screened in the Middle aquifer exceeded their respective MCL. Figure 4-18 depicts the locations of the sixteen monitoring wells and the combined total concentrations of those selected VOCs that individually exceed their respective MCLs in the Middle aquifer.

Well P MW-1S, at the intersection of River and Cove Roads on the SGL Chrome property, yielded water containing PCE and TCE concentrations (230 and 110 µg/L, respectively), well above their respective MCLs, and 1,1-DCE above its MCL. Other nearby wells CC MW-1B, P MW-26M, and P MW-27M yielded water containing TCE concentrations above the MCL (220, 6, and 280 µg/L, respectively). All these wells are finished in layer A-2b. In an off-site area north of Route 90, PCE and (or) TCE were detected at concentrations that exceed MCLs in samples from four wells (Landfill-4, P MW-19M, P MW-21S, and P MW-31M) finished in the Middle aquifer. Landfill-4 and P MW-19M are finished in the lower water-bearing zone (A-2b), the other two wells are finished in A-2a. The water sample from P MW-31M also contained detectable concentrations of 1,1,1-TCA, cis-1,2-DCE, and a concentration of 1,1-DCE well above the MCL. The sample from a fifth well north of Route 90 (P MW-21M) contained no detectable VOCs. The areas north of Route 90 are beyond the OU1 boundary (Figure 1-2) and therefore are not considered part of the Puchack site.

Monitoring well MW-16M, at the intersection of Derousse Avenue and River Road, contained various BTEX compounds, including benzene at 19 µg/L. The sample from well P MW-10M contained benzene at 170 µg/L, well above the New Jersey MCL. The sample also contained ethylbenzene at 190 µg/L and xylene at 230 µg/L; concentrations of both compounds were below their respective MCLs. Additionally, acetone was measured in the sample at 2,600 µg/L, and TCE was present at 3.5 µg/L, above the New Jersey MCL. The BTEX contaminations along River Road are beyond the OU1 boundary (Figure 1-2) and are therefore not considered part of the Puchack site.

Samples from wells east of Route 130, which are beyond the OU1 chromium plume boundary and are, therefore, not considered part of the Puchack site, contained VOC concentrations above the MCLs.

The distribution of VOCs, principally PCE, TCE, 1,1-DCE, and 1,1,1-TCA, is widespread, and, unlike the chromium distribution, does not form a coherent plume (Figure 4-18). There are likely to be multiple plumes of VOCs in the Middle aquifer in Pennsauken Township and vicinity.

4.4.2.3 Intermediate Sand

Figure 4-19 depicts the locations of selected Intermediate Sand monitoring wells which have VOCs exceeded MCLs. The combined total concentration of selected VOCs detected in the Intermediate Sand that individually exceeded their respective MCLs is also depicted in the figure.

TCE was the dominant organic contaminant in water from the Intermediate Sand both in terms of prevalence and magnitude of concentration. Concentrations measured ranged from 0.52 to 140 µg/L in 25 of the 30 wells sampled; concentrations in all but one of the samples in which TCE was detected exceeded the New Jersey MCL (Figure 4-16). Typically, those samples containing detectable amounts of TCE also contained 1,1-DCE, and concentrations of this latter compound also exceeded the MCL in about one third of the samples in which it was measured. Additionally, cis-1,2-DCE was measured (0.2 to 16 µg/L) in many of the same samples in which 1,1-DCE was detected; most concentrations were <2 µg/L. PCE was measured in most samples of water with organic contaminants; concentrations commonly were in excess of the New Jersey MCL. Many of the samples containing the above-mentioned organic compounds also contained relatively small concentrations of 1,1,1-TCA and 1,1-DCA; a few samples contained concentrations of 1,2-DCA below the MCL. Vinyl chloride was not detected in the samples containing other VOCs.

The spatial distribution of VOC-contaminated water (mostly TCE) extends over much the same area as that occupied by the chromium plume, but the extent of the VOC contamination, which may represent several plumes (some of which may have coalesced), extends farther to the north and to the southeast (Figure 4-19). Because there are relatively few wells north of Route 90, it is not clear whether VOC detections at wells P MW-19I, P MW-21I, and P MW-31I represent parts of the same plume, or whether the contamination in water from these wells represents isolated instances. Overall, the areas in which PCE has been detected at levels above the MCL are less extensive than the areas in which TCE has been detected above the MCL (Figure 4-16).

The areas north of Route 90 and southeast of Westfield Avenue are beyond the OU1 boundary (Figure 1-2) and are therefore not considered part of the Puchack site.

4.4.2.4 Lower Aquifer

Figure 4-20 depicts the locations of Lower aquifer monitoring wells which have VOC concentrations exceeded MCLs. The combined total concentrations of selected VOCs in the Lower aquifer that individually exceeded their respective MCLs is also depicted in the figure.

Of 43 wells finished in the Lower aquifer that were sampled during 1999-2001, samples from 29 wells contained one or more VOC in concentrations that exceeded an MCL. Six production wells were sampled in 1999 (Park Avenue wells 2, 5, 4R-A Park Avenue 6, Puchack 1, Marion 1, and Woodbine 1); all except Puchack 1 yielded water containing one or more VOCs (mostly PCE and TCE), some at concentrations exceeding MCLs. Production wells draw water from a greater volume of aquifer than do monitoring wells and thus the water they yield may contain contaminant concentrations that are diluted by uncontaminated water from elsewhere within the contributing area. Therefore, the concentrations of VOCs in samples from these wells may not be representative of the level of contamination present in the vicinity of the well screen.

For all wells sampled during 1999-2001, TCE was the dominant compound, and nearly all detectable concentrations, which ranged from 0.8 to 360 µg/L, exceeded the New Jersey MCL (Figure 4-16). PCE was detected less frequently in the Lower aquifer than in the Intermediate Sand. Detectable PCE concentrations ranged from 0.39 to 13 µg/L; about 60 percent exceeded the New Jersey MCL. Low to moderate (< 30 µg/L) concentrations of 1,1,1-TCA, 1,1-DCA, and 1,1-DCE were measured in samples from 16, 20, and 20 wells, respectively; six samples contained 1,1-DCE in concentrations that exceeded the MCL. Concentrations of cis-1,2-DCE were substantially higher in several samples than in the samples from wells in the Intermediate Sand. Of 18 detections of cis-1,2-DCE, 6 were at concentrations from 8 to 36 µg/L. Additionally, 1,2-DCA was detected in several samples. Vinyl chloride, which had not been detected in samples from wells in shallower water-bearing units, was detected in samples from four Lower aquifer wells (P MW-9D, P MW-19D, P MW-21D, and P MW-31D) with one concentration that exceeded the MCL (from P MW-21D) (Figure 4-16).

Benzene was detected in samples from three wells (P MW-9D, P MW-19D, and P MW-21D); the concentration in P MW-21D was above the MCL. Chlorobenzene and (or) 1,4-dichlorobenzene were detected in the same samples. All three wells are located north of Route 90 (Figure 4-20).

The distribution of chlorinated solvents is widespread in the Lower aquifer, covering an area that partly underlies the areas of VOC contamination in the Intermediate Sand, but is shifted to the east (Figure 4-20). Much of the contamination is coincident with the chromium contamination, but the areal extent of the VOC contamination appears to be much greater than the extent of the chromium plume. The areas north of Route 90 and southeast of Westfield Avenue are beyond the OU1 boundary (Figure 1-2) and are therefore not considered part of the Puchack site.

There are fewer wells in the area north of Route 90 than in the area south of it; consequently, it is not clear whether the VOC contamination detected in water from the Lower aquifer in the areas

north of Route 90 is connected to contamination in water south of Route 90 and east of the Puchack well field. It is likely that, given the potential for multiple VOC sources, the instances of VOCs represent several plumes rather than a single plume. The existence of multiple plumes in the Lower aquifer would, however, indicate that there are multiple points of entry for contaminated groundwater to move into the Lower aquifer from the Intermediate Sand.

4.4.3 OTHER CONTAMINANTS AND CONSTITUENTS IN GROUNDWATER

Samples collected during 2000-2001 were analyzed for major cations and selected metals; other general chemistry constituents such as chloride, sulfate, nitrite, nitrite + nitrate, ammonia, phosphorus, silica, and organic carbon (both TOC and DOC); and VOCs. Field parameters including temperature, pH, SC, DO, turbidity, and Eh were also measured. The results are summarized in Appendix G. Twelve other area wells and one resampled in 2000 had been sampled previously by USGS in 1999. Samples from these wells were analyzed for cations, selected metals (excluding barium and lead), anions, DOC, and VOCs. Results for the 1999 environmental samples are presented in Appendix G.

The most prevalent inorganic contaminant in groundwater in Pennsauken Township and vicinity is chromium. Mercury appears sporadically as a contaminant. Concentrations of other chemical constituents, although generally not contaminants of concern, also are of interest insofar as they can indicate the general geochemical conditions present both in areas of contamination and in areas with ambient water-quality characteristics.

4.4.3.1 Cadmium, Lead, and Mercury

All environmental samples collected during 2000-2001 were analyzed for cadmium. Concentrations of cadmium ranged from 0.06 to 1.6 µg/L; therefore, no concentrations exceeded the MCL of 5 µg/L. Cadmium concentrations in samples from 12 additional wells, collected in 1999 by USGS, were all below the MRDL of 2.5 µg/L in effect at that time.

All environmental samples collected during 2000-2001 were analyzed for lead, whereas those collected in 1999 were not. Lead concentrations ranged from 0.23 to 29.2 µg/L; the latter value, from well SWIM-1, was the only one that exceeded the action level for lead of 15 µg/L (Figure 4-12). Water from this location also contained high concentrations of chloride, so the lead may have been leached from the distribution pipes. Concentrations of lead in water from all other wells were <1 µg/L.

All groundwater samples collected in 1999 and during 2000-2001 were analyzed for mercury. Total mercury concentrations ranged from 0.033 to 3.7 µg/L. Data for four samples were rejected. Mercury concentrations in samples from five wells, CC MW-2D, P MW-4I, P MW-4D, P MW-14, and P MW-22 exceeded the MCL of 2 µg/L (Figure 4-12). Of those wells, three yielded water containing concentrations of total chromium that exceeded the MCL; two other samples (plus duplicates) with mercury concentrations between 0.5 and 1 µg/L were from wells tapping chromium-contaminated water. Background concentrations of mercury in the aquifer system appear to be <0.2 µg/L. The pattern of these occurrences does not seem to be coherent, probably indicating more than a single source. Whether the source(s) of the mercury are anthropogenic or are aquifer materials, or both, currently is not known. A comparison of mercury

values for filtered and unfiltered samples indicates that, at concentrations exceeding the MCL of 2 µg/L, filtered samples contained less mercury than unfiltered samples; therefore, some contaminant-level mercury in the groundwater is likely to be adsorbed to particles/colloids.

4.4.3.2 Iron and Manganese

All groundwater samples collected in 1999 and during 2000-2001 were analyzed for iron and manganese. Figures 4-21 to 4-23 depict the iron concentrations in groundwater from the Middle aquifer, Intermediate Sand, and Lower aquifer, respectively. Data for one iron sample were rejected. Iron concentrations ranged from 12.9 to 62,900 µg/L; the latter value is an extreme outlier. Iron concentrations in most samples were less than 100 µg/L; only 24 samples contained iron > 100 µg/L, of which 11 samples contained iron in excess of the New Jersey Secondary Standard of 300 µg/L, and six of those samples contained iron in excess of 1,000 µg/L. The MRDL for filtered iron typically (although not always) was 100 µg/L; consequently, a comparison between filtered and unfiltered samples with low iron concentrations seldom was possible. At concentrations that exceeded 100 µg/L, filtered samples generally contained less iron than unfiltered samples, indicating that some iron may be adsorbed to particles/colloids. Dissolved iron typically is reduced (ferrous) iron, whereas particulate iron is more likely to be predominantly ferric iron.

Figures 4-24 to 4-26 depict the manganese concentrations in groundwater from the Middle aquifer, Intermediate Sand, and Lower aquifer, respectively. Manganese concentrations ranged from 15.2 to 6,370 µg/L for unfiltered samples. About 78% of the sample concentrations exceeded 50 µg/L, the New Jersey Secondary Standard, while concentrations in samples from 12 wells exceeded 1,000 µg/L. Differences in concentrations between filtered and unfiltered samples were small, and generally within analytical error, indicating that virtually all manganese is present either in dissolved form or adsorbed to colloids smaller than 0.45 µm. A study of metals in filtered fractions (Gibs et al. 2000) indicates that manganese typically is in a dissolved form rather than adsorbed to particles/colloids.

4.4.3.3 Ammonia, Nitrite, and Nitrate

All but two environmental samples (excluding most duplicates) collected during 2000-2001 were analyzed for ammonia (as N), nitrite (as N), and nitrite + nitrate (as N). Samples collected in 1999 also were analyzed for these nutrients. Ammonia concentrations ranged from <0.1 to 4.6 mg/L; 20 of 87 samples (23 %) collected during 2000-2001 contained ammonia concentrations > 1 mg/L. In 13 samples collected during 1999, three contained ammonia concentrations >1 mg/L, which exceeds the median ammonia concentration (0.25 mg/L) for the aquifer system in southwestern New Jersey (Fusillo et al. 1984).

Nitrite concentrations ranged from 0.005 to 0.091 mg/L. Nitrite was not detected in the majority of samples, and typically was low or not detected in samples with large ammonia concentrations. Nitrite + nitrate concentrations, which were predominantly nitrate, ranged from <0.1 to 12.8 mg/L; the latter concentration (in the sample from P MW-21S) exceeds the MCL of 10 mg/L. Nitrite + nitrate concentrations in samples from two other wells (8.8 and 9.3 mg/L) approach the MCL. About 56% of the samples contained nitrite + nitrate concentrations of 1 mg/L or greater, which exceeds the median nitrite + nitrate concentration (0.1 mg/L) for the aquifer system in

southwestern New Jersey (Fusillo et al. 1984). In those samples with high ammonia concentrations, nitrite + nitrate concentrations typically were low or undetectable.

4.4.3.4 Chloride, Sulfate, and pH

Chloride and sulfate were measured in all samples collected in 1999 and during 2000-2001. Concentrations of chloride ranged from 3.4 to 274 mg/L; the latter concentration (in the sample from P MW-20I) exceeds the New Jersey Secondary Standard of 250 mg/L. Chloride data for six water-supply wells, sampled since 1932 in some cases, are reported by Fusillo et al. (1984). These data indicate a general increase in chloride concentration over time, a trend that continues to the present. The largest increase in chloride concentration was from 3.0 mg/L in 1980 to 106 mg/L in 2000 (well SWIM-1), which may reflect a difference in where in the distribution system the sample was collected in 2000. The incidence of elevated chloride levels is most apparent in water from the Middle aquifer, where 58 percent of samples collected during 2000-2001 contained chloride concentrations > 20 mg/L. Only 30 percent of samples from the Intermediate Sand and 18 percent of samples from the Lower aquifer contained chloride concentrations > 20 mg/L. If elevated chloride concentrations are used as a measure of anthropogenic impact on water quality, water in the Middle aquifer shows the most widespread evidence of anthropogenic inputs.

Concentrations of sulfate ranged from 1.9 to 189 mg/L. Concentrations in most samples (73%) were in the 10 to 50 mg/L range. Concentrations in four water-supply wells sampled in 1966 or 1980 (Fusillo et al. 1984) had increased slightly by 1999.

The pH of groundwater was measured in the field during 1999-2001 and ranged from 4.43 to 7.06. The pHs in nearly 80 percent of the samples collected during this time period were 5.0 or higher. Figures 4-27 to 4-29 depict the measured pH in groundwater from Middle aquifer, Intermediate Sand, and Lower aquifer, respectively.

4.4.4 CHANGES IN CONTAMINANT LEVELS WITH TIME

Groundwater sampling by the USGS in Pennsauken Township and vicinity has been carried on since 1997, and sampling of some water-supply wells and monitoring wells was done by or for other agencies prior to that date. It is, therefore, possible to evaluate changes in contaminant concentrations with time in areas where wells have been sampled for several years.

4.4.4.1 Chromium

Table 4-7 summarizes changes in chromium concentrations from 1998 to 2001.

In the Middle aquifer, two wells next to the Pennsauken landfill (Landfill-4 and Landfill-6, both off-site wells) were sampled during 1997-98, and found to yield water with chromium concentrations that exceeded the MCL. Well P MW-1S, located at the SGL Chrome property southwest of the Puchack well field, also was sampled during 1997-98. Two of these wells (Landfill-4 and P MW-1S) were resampled during 2000-2001. Results from the 2000-2001 sampling indicated that total chromium concentrations in water tapped by both wells had

decreased over time; concentrations decreased from 341 to 290 µg/L in water from Landfill-4 and from 9,720 to 8,010 µg/L in water from P MW-1S.

In the Intermediate Sand, three wells south, southeast, and southwest of the Puchack well field (CC MW-1A, MW-2A, and P MW-5I) were sampled during 1997-98, and found to yield water with chromium concentrations well above the MCL. Results from sampling these wells during 2000-2001 indicate that concentrations have decreased substantially in water from all three wells, from 4,130; 9,070; and 8,100 µg/L, respectively, to 1,730; 3,570; and 3,010 µg/L respectively (Table 4-7 and Figure 4-30).

Well P MW-14 tapped water in the Intermediate Sand with no detectable concentrations of chromium in 1998, but in 2001, the total chromium concentration was 1,720 µg/L. This is the only well sampled more than once where an increase in chromium concentration was noted; the increase likely is the result of a change in the direction of plume migration since pumping at Puchack-1 ceased in 1998.

In the Lower aquifer, two monitoring wells (P MW-5D and P MW-6D) were sampled during 1997-98 and again during 2000-2001. As in the Middle aquifer and Intermediate Sand, results from sampling these wells in 2000-2001 indicate that chromium concentrations have decreased substantially, from 904 and 3,320 µg/L, respectively, to 384 and 1,450 µg/L, respectively (Figure 4-30).

Water-supply wells in the Puchack well field were sampled between 1981 and 1998. Chromium concentrations (including hexavalent and total chromium) measured in water from wells Puchack-1, Puchack-2, Puchack-3, and Puchack-5 increased during the 1980s. Concentrations decreased in water from Puchack-7, however, and were not detected in October 1989 (NJDEP 1990a). Pumping ceased at all but one well (Puchack-1) in the well field in 1984, and concentrations measured about a decade later in water from four non-pumping wells generally were less than those measured in 1989, although still above the MCL in some cases.

The overall pattern observed is that chromium concentrations in groundwater are decreasing with time. This indicates that less contaminated water has replaced more contaminated water and the cores of the plumes have shifted, and (or) chemical reactions between water and aquifer materials involving either adsorption of Cr (VI) to aquifer materials and (or) reduction of Cr (VI) to Cr (III) and subsequent precipitation of Cr (III)-bearing solids have resulted in removal of dissolved chromium in groundwater. These mechanisms are discussed in detail in Section 5.0.

4.4.4.2 Organic Contaminants

A comparison of results of VOC analysis for samples collected from 16 wells during 1997-98 and results for samples collected in 2000-2001 from the same wells are provided in Table 4-8. The comparison indicates that concentrations of TCE and PCE have decreased with time in the water tapped by many of these wells, most of which were finished in the Middle aquifer or the Intermediate Sand. The change in the concentrations of VOCs with time commonly was not large, but concentrations of benzene decreased substantially, from 1,200 to 170 µg/L, in samples from Middle aquifer well P MW-10M. TCE concentrations in samples from Lower aquifer well P MW-4I, sampled in December 1999 and again in August 2000, decreased from 130 to 52 µg/L.

In the samples from Intermediate Sand well P MW-12M in the southeastern part of the study area, however, concentrations of PCE and TCE increased slightly. These and other changes in VOC concentrations are listed in Table 4-8. In some cases, changes in concentration with time may result from a shift in the position(s) of the VOC plume(s) or changes in inputs from the sources, but also may be the result of degradation of the organic compounds. The processes by which change occurs are discussed in greater detail in Section 5.0.

4.5 POTENTIAL SOURCES OF CONTAMINATION

In a highly industrialized area such as Pennsauken Township, the potential exists for both inorganic and organic contaminants to be contributed to soils by operations that use hazardous materials on a regular basis. The permeable nature of the soils and most sediments into which such contaminants might be introduced increases the potential for contamination of the groundwater beneath. The current detailed study of the properties of the geologic units indicates that previous assumptions of clay layers representing areally extensive barriers to contaminant migration are not always valid. Tracing the pathways contaminated groundwater apparently has taken through the aquifer system has indicated possible surficial sources, as has soil sampling, albeit limited, at various industrial/commercial properties located within the outcrop areas of the mostly unsaturated Upper aquifer and the Middle aquifer.

Currently, the determination of potential sources of organic contaminants in the vicinity of the Puchack well field can be based only on a limited number of soil samples that clearly indicate the presence of organic compounds. The likely locations of other potential source areas can be deduced from the distribution of organic contaminants in groundwater from the first water-bearing units in the study area; these are the Upper aquifer in the easternmost part of the study area, and the Middle aquifer over the rest of the study area.

Five industrial or commercial properties were investigated by EPA during the RI as potential sources of groundwater contamination. These properties are Advanced Process Supply, King Arthur, Mercon, SGL Chrome, and Supertire. The results of the investigations conducted by EPA are summarized in Section 4.2 and are discussed below for their potential contribution to groundwater contamination. Additionally, another area (Davidson Pacific Wood Products property) that was not investigated during the RI was also discussed for potential contribution to groundwater contamination based on previous and current groundwater results.

4.5.1 ADVANCE PROCESS SUPPLY PROPERTY

4.5.1.1 Chromium

Monitoring wells were previously installed at the APS property and these wells were sampled during January 1990. Two wells screened at about 60 feet bgs yielded water containing 40 and 82 µg/L of total chromium (Environmental Strategies Corporation 1990). These concentrations do not exceed the New Jersey MCL, but are substantially above background concentrations. Results of recent soil sampling (Lockheed Martin 2000) indicate that there are elevated concentrations of total chromium present in some of the soils and sediments collected at the APS property, the highest concentration (55 mg/kg) being found in a deep sample. No samples have been collected at the water table, however. It is not known conclusively whether the chromium

in these soils and sediments has leached into groundwater at this site, although this appears possible, and there are no recent data to indicate whether groundwater underlying the property still contains above-background concentrations of chromium.

4.5.1.2 Organic Contaminants

Detectable levels of organic compounds at the APS property do not appear to extend below 9 feet bgs; evidence of deeper organic contamination at this location or at others on the property would be needed to consider these soils a source of organic groundwater contamination.

4.5.2 DAVIDSON PACIFIC WOOD PRODUCTS PROPERTY

4.5.2.1 Chromium

There are indications that chromium-contaminated water exists, or has existed, elsewhere in the Middle aquifer in a part that is not tapped by the recently installed monitoring wells. Samples collected in August 1990 from two of three wells finished at 92 feet bgs at the former Davidson Pacific Wood Products property contained total chromium concentrations (500 and 120 µg/L) that exceeded the current New Jersey MCL. The sample from the third well contained chromium above background levels (31 µg/L) (Geotech Environmental, Inc. 1990). The sample containing 500 µg/L of chromium also contained lead at 53 µg/L (Geotech Environmental, Inc. 1990). Hexavalent chromium was not detected at 25 µg/L (a high MRL) in filtered groundwater samples collected in February 1991 (Geotech Environmental, Inc. 1991); total chromium does not appear to have been measured at that time. The vertical distribution of chromium-contaminated water was not determined at this location, nor was the lateral extent delineated beyond the boundaries of the property.

Chromium concentrations in soil borings ranged from 1.8 to 15 mg/kg, and thus were within or near the upper limit of naturally occurring concentrations in local soils. Consequently, these soils data do not indicate that the chromium-contaminated water is attributable to surficial contamination at the Davidson Pacific Wood Products property. Therefore, it appears that the wells may have tapped into a chromium plume that originated elsewhere. The degree to which the Middle aquifer water at this location may be still contaminated by chromium is unknown. Mercury concentrations that exceeded the MCL also were reported for samples from the three original monitoring wells at this property; but, because a similar level of mercury was measured in the field blank, it appears that these results are not valid (Geotech Environmental, Inc. 1990, Appendix HI).

4.5.2.2 Organic Contaminants

In October 1990, monitoring wells at the Davidson Pacific Wood Products property yielded water containing VOCs and SVOCs. The individual compounds were not all identified, but toluene, xylene, and ethylbenzene were reported. Two monitoring wells, MW-02 and MW-04, were sampled and toluene concentrations ranged from 100 to 540 µg/L, ethylbenzene concentrations ranged from 4 to 9 µg/L, and xylene concentrations ranged from 35 to 66 µg/L. In the April 1991 sampling event, the same monitoring wells were sampled and toluene concentrations ranged from 53 to 920 µg/L, ethylbenzene concentrations ranged from 2 to 8.5

µg/L, and xylene concentrations ranged from 33 to 53.6 µg/L (Geotech Environmental, Inc. 1990). Thus, in addition to chromium contamination, BTEX and other organic compounds were present in the Middle aquifer at this location a decade or more ago. The source of the organic contaminants has not been identified.

4.5.3 KING ARTHUR PROPERTY

4.5.3.1 Chromium

The King Arthur property was not considered a source of chromium in a previous investigation insofar as water samples from shallow wells on the property did not contain detectable concentrations of chromium, although water from deeper wells finished below a clay layer contained substantial amounts (from 93 to 4,070 µg/L) (James C. Anderson Associates Inc. 1991). Davidson Pacific Wood Products, thought to be upgradient from King Arthur, was suggested as a possible source; the existence of a “breach in the clay layer” also was suggested (James C. Anderson Associates, Inc. 1991). On the basis of recent sampling (CDM 2001a and CDM 2001b), chromium concentrations in shallow soils at King Arthur are above expected background levels, but deeper soils and sediments (below 10 feet) appear to contain chromium at background levels. Therefore, as indicated previously, the plume of chromium-contaminated groundwater beneath the King Arthur property appears to have originated elsewhere because, based on the limited soils and sediment sampling, evidence of chromium moving through the surficial soils to the water table is lacking.

4.5.3.2 Organic Contaminants

The traces of toluene in two samples from the King Arthur property are unlikely to represent a source of groundwater contamination unless further sampling at that property reveals that more substantial concentrations of VOCs are present. Sample data collected from shallow monitoring wells (completed in the Middle Aquifer) at the King Arthur property in 1991 showed concentrations of TCE ranging from 9 to 644 µg/L and 1,1,1-TCA concentrations ranging from 5 to 94 µg/L (James C. Anderson Associates, Inc. 1991). TCE was detected in 1991 in samples from the deep wells finished in the Intermediate Sand but at lower concentration than those observed in the shallow monitoring wells. The source or sources of these VOCs was not clear in 1991, nor is it now. Based on site definition, the high historical VOC concentrations (e.g. TCE as high as 664 ppb) in the vicinity of King Arthur would appear to make this a VOC hot spot within the known extent of the chromium plume.

4.5.4 MERCON PROPERTY

4.5.4.1 Chromium

The Mercon property was considered a possible source of chromium contamination on the basis of previous industrial operations (Enviro-Sciences, Inc. 1990). Nevertheless, results of soil sampling do not indicate that chromium concentrations in soils are greatly elevated above expected background levels. Therefore, the data collected to date do not indicate that the Mercon property is a likely source of chromium contamination to groundwater.

4.5.4.2 Organic Contaminants

The concentrations of 1,1,1-TCA from two borings at the Mercon property were low, but the compound had penetrated as deep as 57 feet bgs, which appears to be just below a perched water table. The data do not indicate the Mercon property as a source of organic contamination to groundwater.

4.5.5 SGL CHROME PROPERTY

4.5.5.1 Chromium

On the basis of recent sampling, discussed in Section 4.2, soils in the areas adjacent to P MW-1S contain concentrations of chromium that greatly exceed expected background levels; samples containing high chromium concentrations were collected throughout the soil/sediment column and at or below the water table. The fate and transport of chromium is discussed in Section 5.2. Historical information indicates that a company called Du-Mor purchased the current SGL property from Nenin H. McKay on January 21, 1963 (NJDEP 1990b). The quantity of wastewater that was discharged between 1963 and 1969 is unknown. SGL Chrome purchased the property from Du-Mor Hard Chrome and consolidated Du-Mor with Modern Hard Chrome of Camden. SGL Chrome ran a nickel and chrome plating shop which began operation in 1969 and terminated in 1981. SGL Chrome generated over 9,000 gallons of plating wastewater per day, or 3.3 million gallons per year. Based on this information, an estimated 39 million gallons of wastewater (9,000 gallons per day over 12 years) was discharged to two underground septic systems.

Based on the nature of the operation and the investigation results, it is likely that significant portions of the chromium was introduced to the soils in the hexavalent form, which is highly soluble and can move easily through the environment. From the septic system the wastewater and the chromium moved down through the soil column and into the aquifer below. Chromium contamination was detected in Puchack 4R/6-70 in the early 1970s. Sulfate, as known to be in the SGL discharge, greatly increases chromium mobility in groundwater. The distance between SGL Chrome and Puchack 4R/6-70 is approximately 3,000 feet. Therefore, the chromium contaminated groundwater was traveling at between several hundred to a thousand feet per year. Several factors could contribute to this high migration velocity: groundwater velocity was much higher when Puchack wells were pumping at full capacity; the large quantity of waste water quickly depleted the adsorptive and reductive capacities of the soil particles; the discharge created a higher hydraulic gradient; sulfate, as known to be in the SGL discharge, greatly increase the chromium mobility in groundwater; and portions of the contaminated groundwater could conceivably have migrated through preferential channels in the aquifer. General use of the Puchack well field was terminated in 1984.

Soil samples collected during drilling of monitoring wells installed in 1982 on the property indicate the presence of large concentrations (3,500 mg/kg) of total chromium in surficial soils at one location near ERTSB-08; elevated chromium concentrations (between 20 and 100 mg/kg) continued with depth to 67 feet bgs. Hexavalent chromium, however, was not detected (John G. Reutter Associates 1982). An area of chromium-contaminated soil on the property was capped with bituminous concrete in 1983 (Stablex-Reutter Inc. 1984).

Of the two monitoring wells at SGL Chrome sampled during 1982, shallow well 1 (screened at 35-55 feet bgs) yielded chromium contaminated water that increased over a five-month period from 120 to 5,500 µg/L. Most of the chromium was Cr (VI). Monitoring well 3 (screened at 65-85 feet bgs) yielded water with concentrations of total chromium that first increased (60 to 1,000 µg/L) and then declined to below the detection limit of 50 µg/L over the same five-month period (John G. Reutter Associates 1982). Well 3 did not yield chromium-contaminated water in late 1983 or in 1984 (Stablex-Reutter Inc. 1984), nor did it in 1994. Well 1, which was later sealed, was screened above a clay layer that was thought to serve as a barrier to downward migration of contaminants (John G. Reutter Associates 1982). Well 1A, installed in 1982 as a replacement for well 1, was screened from 70.5 to 90.5 feet bgs; this well, when sampled, did not yield chromium-contaminated water (Stablex-Reutter, Inc. 1984). Results from sampling well P MW-1S (located immediately downgradient from former Well 1), however, confirm the earlier results from Well 1 (now sealed) that indicate substantial contamination of groundwater with chromium at a depth of about 55 feet bgs.

Currently, it is not known precisely where the chromium-contaminated water has moved from the top of the clay layer (presumably C2a) downward to the Intermediate Sand. Nor is it known whether the Intermediate Sand plume of chromium-contaminated water is now detached from the small plume in the Middle aquifer at P MW-1S, or whether contaminated water at P MW-1S continues moving eastward and down into the Intermediate Sand. If the former, it is not known if chromium-contaminated water at P MW-1S is moving in a direction other than to the northeast, now that pumping from the Puchack well field has ceased, and regional water levels generally are rising, as described in Section 3.0.

4.5.5.2 Organic Contaminants

A variety of VOCs were detected in soils at the SGL Chrome property. Concentrations generally were low but TCE was measured at 97 µg/kg at a depth of 59 feet bgs, which is below the water table. Sampling of a “deep” monitoring well at the property (Well no. 3, which probably is finished in the Intermediate Sand), yielded water in August 1982 containing 20 µg/L of TCE (John G. Reutter Associates 1983). Benzene, PCE, and toluene were detected in a sample from shallow (Middle aquifer) Well no. 1. Benzene, 1,1,1-TCA, TCE, PCE, and toluene were detected in a sample from shallow (Middle aquifer) Well no. 1 in June, 1982; trans-1,2-DCE, 1,1,1-TCA, TCE, PCE and toluene were detected in July, 1982, and the same compounds, except toluene, were detected again in August, 1982. The concentrations in samples from the July and August sampling events were substantial; in August, reported concentrations were 110 µg/L for trans-1,2-DCE, 220 µg/L for 1,1,1-TCA, 510 µg/L for TCE, and 60 µg/L for PCE (Stablex-Reutter Inc. 1982). In 1998, VOC concentrations in water from this well were undetectable, with the exception of a trace (0.6 µg/L) of methyl-tertiary butyl ether (MTBE) (Walker and Jacobsen, in press).

4.5.6 SUPERTIRE PROPERTY

4.5.6.1 Chromium

Based on the recent sample results that produced limited detection of chromium in soil and low detection of chromium in the groundwater, Supertire is likely not a chromium source for groundwater contamination.

4.5.6.2 Organic Contaminants

Historical groundwater data at Supertire indicates that 1,1,1-TCA and 1,1-DCE were detected on site in the groundwater at several locations. In 1998 USGS sampled Supertire MW-2D well in the Middle aquifer and found 1,1-DCE at an estimated concentration of 3,580 µg/L and 1,1,1-TCA at an estimated concentration of 12,500 µg/L. These constituents were also identified in wells down gradient of the Supertire site, including P MW-12S, P MW-30S, and P MW-29S for example.

Concentrations of 1,1,1-TCA were high in soils at the Supertire property and had penetrated to 52 feet bgs, where a concentration of 11,000 µg/kg was measured just below the water table. Samples of groundwater collected from three boreholes at the time of the soil sampling at the Supertire property contained 1,1,1-TCA at concentrations ranging from 67 µg/L to 390,000 µg/L. This compound clearly had reached the groundwater system at this location, as had 1,1-DCE, measured in concentrations up to 8,800 µg/L.

Overall, based on these preliminary data, soils at Supertire appear to be a source of 1,1,1-TCA and 1,1-DCE to groundwater in Pennsauken Township.

4.5.7 SUMMARY OF POTENTIAL VOC SOURCES AND HOT SPOTS

On the basis of the spatial distribution and types of compounds present, there appear to be multiple sources of VOCs in or near the study area (Figure 4-17).

Potential VOC sources and hot spots within the OU1 boundary:

- SGL (P MW-1S and P MW-26M)
- King Arthur (P MW-27M, P MW-27I, CC MW-1B, KING ARTHUR 5D, KING ARTHUR 6D, and CC MW-1A)
- Mercon (P MW-24I, P MW-4D, CC MW-2A AND CC MW-2D)
- Hot spots at P MW-14 and P MW-14I; P MW-23M and P MW-23I; P MW-15M and P MW-15I; CC MW-4I and CC MW-4D; P MW-5I N and P MW-5D; P MW-6I and P MW-6D; P MW-11I and P MW-11D; P MW-22I and P MW-22D; and P MW-17I.

Potential VOC sources and hot spots outside of the OU1 boundary and are not considered part of the Puchack site:

- BTEX hot spots appear to be located along River Road (P MW-16M, P MW-16I, and P MW-10M).

- VOC contamination southwest of Westfield Avenue: Supertire (BELL IND-1), Horner Mack (P MW-34M, P MW-34I, and P MW-34D), and hot spots at P MW-30S and P MW-30I; P MW-12S, P MW-12M, and P MW-12D; P MW-12EAST-S; P MW-29S, P MW-29I, and P MW-29D; P MW-35I; and P MW-13D.
- VOC contamination north of Route 90: Pennsauken Landfill (LANDFILL 4); hot spot at P MW-19M, P MW-19I, and P MW-19D; Penler Anodizing (P MW-21S, P MW-21I, and P MW-21D), and hot spot at P MW-31M, P MW-31I, and P MW-31D; and hot spot at P MW-20D.

5.0 CONTAMINANT FATE AND TRANSPORT

This section examines the chemical and physical processes that affect both the fate and transport of inorganic and organic contaminants in groundwater at the Puchack Site. As with the prior sections, this section focuses on chromium, the primary contaminant of concern at the Puchack Site. The fate and transport of a suite of VOCs is also considered, with emphasis on the most prevalent: PCE, TCE, and 1,1,1-TCA, and their degradation products.

5.1 INORGANIC CONTAMINANTS

The principal inorganic contaminant in groundwater at the Puchack Site is chromium, with the hexavalent form being the major contaminant of concern. The chromium currently measured in the Puchack Site's groundwater apparently entered the aquifer system as a contaminant introduced at or near the land surface. It is highly likely that the chromium was introduced to the soils in the hexavalent form. Species containing Cr (VI) tend to be highly soluble (as H_2CrO_4 , HCrO_4^- , CrO_4^{+2} , or $\text{Cr}_2\text{O}_7^{2-}$), and can move easily through the environment. The fate of chromium is critically dependent upon its interactions with other chemical constituents, principally those in soils and aquifer sediments. To the degree that these interactions do or do not retard the progress of chromium through the soils and aquifers, the chemical interactions affect the transport of this contaminant.

5.1.1 CHROMIUM CHEMISTRY

5.1.1.1 Introduction

This section describes the basic chemistry of chromium and its interactions with other chemical constituents that account for the behavior of this metal in the natural environment. Chromium can exist in several oxidation states (+6, +5, +4, +3, -2), but, of these forms, some are transitory or occur under strongly reducing conditions, and only Cr (VI) and Cr (III) typically occur in the environment (Palmer and Puls 1994; Moore and Ramamoorthy (1984). Cr (III) is the more common form of naturally occurring chromium, principally in minerals such as chromite. Cr (III) species typically are relatively immobile in the environment; except at low pH, concentrations of Cr (III) species tend to be low in natural waters, owing to their low solubility, although particulate Cr (III) may be present (Palmer and Puls 1994; Faust and Aly 1981). Cr (VI) is the more mobile and more toxic of the chromium forms, occurring in solution as the anions chromate (CrO_4^{2-}) or bichromate ($\text{Cr}_2\text{O}_7^{2-}$) (Palmer and Puls 1994). As a solid, Cr (VI) forms chromate minerals, but these are rare.

The chemical behavior of aqueous chromium in soils and in an aquifer is complicated and interactive between soil or sediment and water, and cyclic in some reactions that occur as they relate to solid and dissolved phases and the various oxidation states present. In soils, Cr (VI) species may be reduced to Cr (III) by ferrous iron [Fe (II)] in minerals or solution, by reduced manganese, reduced sulfur, and (or) fulvic and humic acids in organic matter, while, at the same time, Cr (III) species may be oxidized to Cr (VI) by oxidizing compounds that exist in the soil (commonly manganese dioxide, MnO_2). Details of these processes are not completely understood: some studies indicate that Fe (II) in solution is an effective reductant (Buerge and Hug 1999), whereas others indicate reduction is by Fe (II) in solid phases (Palmer and Puls

1994). It is suggested that, in acidic environments, Fe (II) is less effective in reducing Cr (VI) than are other reductants (Pettine et al. 2002). The same redox reactions that occur in soils can take place in aquifers, although organic matter is less likely to be an important reductant in most aquifer sediments.

The kinetics of the redox reactions involving chromium have been investigated. The reduction of Cr (VI) can be rapid (within minutes) in acidic soils and sediments (Bartlett 1991); the reaction proceeds despite the presence of DO (Eary and Rai 1988). Experimental results for the oxidation of Cr (III) by manganese oxides are mixed; some showing the process is rapid (Bartlett 1991), particularly when the amount of MnO₂ is large relative to chromium (Moore and Ramamoorthy 1984). Other studies indicate the process is relatively slow, and that DO is a less effective oxidant than is reduced manganese (Palmer and Puls 1994).

Although Cr (VI), as chromate, is easily dissolved, it can precipitate as chromate salts with barium, calcium, iron, or lead can adsorb on oxides and hydroxides (Buerge and Hug 1999). Competition with other anions, principally phosphate, but also carbonate, nitrate, and sulfate, can prevent adsorption of chromate ion on hydroxide substrates (Stollenwerk and Grove 1985). Cr (III) precipitates as Cr(OH)₃ at pHs above 5, or coprecipitates with iron hydroxides (where it substitutes for iron); both processes generate H⁺, thus decreasing the pH (Seaman et al. 1999).

5.1.1.2 Relation of Chromium to Other Constituents in Groundwater

Relations between contaminants and other constituents can be indicative of interactions between the contaminants and components of the geochemical environment into which they have entered. These interactions are parts of processes that may substantially affect the fate and transport of contaminants through the aquifer system. Materials in the aquifer sediments that could supply constituents that react with chromium include iron-bearing minerals such as biotite, pyrite, and iron hydroxides, also lignite that can contribute reduced sulfur and carbon. Although not identified as yet, manganese oxides or hydroxides may also be present.

Because iron interacts with chromium in several ways either through redox reactions, adsorption, or co-precipitation, the relations between iron and chromium are of particular importance, as they can provide clues to the chemical reactions that have taken place.

Figures 4-21 to 4-26 depict the iron and manganese concentrations in groundwater from the Middle aquifer, Intermediate Sand, and Lower aquifer, respectively. As with previous sampling results, the highest chromium concentrations were in water that contained low concentrations of both iron and manganese. Conversely, only very low concentrations of chromium were present in water with high concentrations of iron and manganese. Nevertheless, low concentrations of chromium are also present in water with low concentrations of iron and manganese. Although reactions between chromium and iron and (or) manganese would be anticipated, the data do not unequivocally indicate that such reactions have taken place. Likely reactions involving the Cr (VI) in the groundwater plumes include adsorption of Cr (VI) to iron hydroxides and reduction of Cr (VI) by Fe (II) in various minerals or in solution.

The products of the reduction of Cr(VI) by Fe (II) are Cr(III) and the ferric iron Fe (III). Fe (III) typically forms insoluble iron oxides and hydroxides, and Cr (III) may remain in solution as a

hydrated species at low pH, may precipitate with the Fe (III) as a solid solution, may precipitate as a chromium hydroxide at mildly acidic to alkaline pH, or bind to organic matter (Palmer and Puls 1994; Buerge and Hug 1999).

Chromium concentrations in the groundwater plumes ($> 100 \mu\text{g/L}$) and those on the plume fringes (between 20 and $100 \mu\text{g/L}$, located northeast of the plumes) were associated with low ($< 2 \text{ mg/L}$) concentrations of DO. Figures 5-1 to 5-3 depict the DO concentrations in groundwater from the Middle aquifer, Intermediate Sand, and Lower aquifer, respectively. The only exception to this pattern was groundwater from P MW-1S, completed in the Middle aquifer, on the SGL Chrome property. This sample contained the highest concentration of chromium measured during the two sampling events conducted in the period 1998 and 2001. The DO concentration in the sample from P MW-1S was slightly higher (3.48 mg/L) than the $< 2 \text{ mg/L}$ measured in water from other wells that intercepted the chromium plumes in the study area. However, since the DO concentration in an earlier sample from P MW-1S was $< 1 \text{ mg/L}$ (Walker and Jacobsen, in press), the higher value in 2001 may be a sampling artifact, as the well yielded little water during the sampling process.

Sulfate concentrations were higher (111 mg/L) in water from P MW-1S than from most other wells in the area. Low or undetected concentrations of total chromium were associated with a wide range of sulfate concentrations. However, it is observed that in samples with total chromium concentrations above background or its MCL, sulfate concentrations tended to increase as chromium concentrations increased. There appear to be two groups of water samples; those with concentrations of total chromium of about $5 \mu\text{g/L}$ or less which show no trend with sulfate concentration, and those above $5 \mu\text{g/L}$, which span three orders of magnitude, and show an increasing trend with sulfate concentrations (Figure 5-4). Because high concentrations of sulfate are associated with both background and contaminant-level concentrations of chromium, it is not known if the elevated sulfate concentrations associated with the chromium plumes are the result of sulfate entering the aquifer with the chromium (that is, as wastes from the source(s)) or are the result of reactions between the chromium-contaminated groundwater with sulfur-bearing materials in the aquifer sediments, or both. Sulfate may play an important role in the fate and transport of chromium, as it may compete with chromate, Cr (VI), for sorption sites, thus enhancing the mobility of Cr (VI).

There were no apparent relations of chromium concentrations with concentrations of other chemical constituents, or with pH or specific conductance. Oxidation/reduction potential values spanned a wide range of voltages for low concentrations of total chromium, but tended to increase as chromium concentrations $\geq 10 \mu\text{g/L}$ increased.

5.1.2 FATE OF CHROMIUM IN GROUNDWATER

The fate of chromium in groundwater depends on its interactions, or lack thereof, with other chemical constituents in the aquifer. A decrease in chromium concentrations at a specific location over time can be the result of:

- Advection (i.e., the plume of contaminated water has moved to another location), dispersion, and dilution
- Adsorption to aquifer materials

- Chemical reduction by aquifer materials or dissolved constituents in groundwater

Any mass of chromium lost from the aqueous phase likely exists in some solid phase, if chemical reactions involving adsorption or precipitation are demonstrated. The investigation of the Puchack Site groundwater contamination indicate substantial decreases in chromium concentrations over time; the mechanisms for reduction in chromium concentrations are discussed in the following sections.

5.1.2.1 Advection, Dispersion, and Dilution

Because the groundwater is continually moving, the decrease in chromium concentration at any well could represent the physical replacement (advective reduction) of more contaminated water with less contaminated water from an upgradient part of the aquifer. The upgradient water may be less contaminated because:

1. The magnitude of releases from the source has varied over time.
2. Groundwater movement has carried contamination as a slug through the water-bearing units.
3. Chemical or physical reactions have occurred to remove chromium from the aqueous phase.

The changes in concentration of chromium over time may result from one of these factors, or, most likely, from a combination of these factors.

Dilution and dispersion of the contaminant plume occur as it migrates with the prevailing groundwater flow. Dilution occurs because the contaminated groundwater mixes with uncontaminated water. Dispersion is caused by small to large scale differences in hydraulic permeability along the migration pathway, which result in spreading of the contamination longitudinally ahead of the average flow, as well as laterally. Dispersion is proportional to groundwater velocity. Both dilution and dispersion cause a decrease in contaminant concentrations, compared to the concentration of the original source loading into the groundwater flow system.

Dilution and dispersion are enhanced by pumping. As a plume approaches a pumping well, groundwater velocity increases, resulting in more dispersion. In addition, higher volumes of uncontaminated groundwater are mixed with the plume as the flow converges into the pumping well. Because the Puchack well field captured a portion of the chromium plume, these pumping-induced effects were known to occur.

In the Puchack well field area, uncontaminated groundwater flows laterally into the plume area from the Delaware River as the ultimate source of lateral inflow. Uncontaminated water also flows vertically downward due to leakage from overlying units, with rainfall infiltration as the ultimate source. Groundwater flow modeling by the USGS has shown that these two sources of groundwater are of the same order of magnitude in the plume area. When the Puchack wells were pumping, the decrease in concentration from dilution and dispersion were more pronounced.

5.1.2.2 Adsorption

In addition to advection, dispersion, and dilution, adsorption of Cr (VI) on aquifer materials also could cause aqueous chromium concentrations to decrease over time. Hexavalent chromium typically is present in groundwater as an anion, adsorption of which would be likely under the moderately acidic conditions that prevail in much of the Potomac-Raritan-Magothy aquifer system. The aquifer sediments cannot be considered a permanent repository for adsorbed Cr (VI) because the chromium could desorb if either groundwater pH increased or other anions competed for sorption sites on the sediment.

The adsorption/desorption process for inorganics is generally dependent upon the organic carbon, silt, and clay content of the soils, the pH of the groundwater, and particular species present for a given inorganic constituent. The equilibrium species distribution is also dependent upon the “release state” (e.g., waste containing Cr (VI)), groundwater pH, oxidation/reduction conditions, and other water quality factors (e.g., ferrous iron concentration) affecting constituent speciation in general.

The adsorption/desorption process is expressed using soil/water partition coefficient (K_d) and retardation factor (R) with the following relationship.

$$R = 1 + (\rho_B/n) \times K_d$$

Where:

- R = Retardation factor (dimensionless)
- ρ_B = Bulk density of the soil (assume 1.5 grams per cubic centimeter (g/cm^3)) (EPA 1996)
- n = Water filled porosity (assume 0.3)
- K_d = Soil/water partition coefficient (L/kg)

A site specific soil/water partition coefficient can be approximated using the sediment and groundwater results obtained during the RI. The coefficient is the ratio between the sediment concentration and groundwater concentration obtained from the same location.

In all cases except for one, the calculated K_d and retardation factors are much higher for total chromium than for Cr (VI). Total chromium measured in sediments may include Cr (III) and Cr (VI), as evidenced by lesser concentrations of hexavalent chromium than total chromium. In most of the groundwater samples, however, hexavalent and total chromium concentrations are similar, indicating that chromium (III) commonly is not present in solution. Note that the calculations above only provide an indication of the magnitudes of the K_d and retardation factors. Also note that the field K_d 's are not true partition coefficients for several reasons, which include mechanism besides adsorption (reduction and precipitation) is at work and equilibrium conditions may not exist.

Henderson (1994) has determined an average retardation factor of 4 for chromium in the sand and sandstone Trinity aquifer, which is less than the above calculated retardation factors for total chromium and Cr (VI). The Potomac-Raritan-Magothy aquifer is more acidic (lower pH) than the Trinity aquifer; therefore, retardation of chromium would be expected to be greater.

5.1.2.3 Chemical Reduction

If the observed decreases in chromium concentrations in groundwater are primarily caused by chemical reduction of Cr (VI) and precipitation of Cr (III), there should be a rate at which the reduction takes place that is congruent with rates already determined by laboratory and field studies. Henderson (1994) indicates that a first-order rate constant is applicable to the reduction process on the basis of experimental and field data, and shows rate constant k (hr^{-1}) as a function of pH. Rate constant k increases from 1×10^{-5} to 1×10^{-3} at pHs from about 8 down to about 4.5; reduction rates decrease linearly with increasing pH. Henderson (1994) uses the following equation to calculate the rate constant:

$$k = (2.303/t) \log [C_o/C_t]$$

Where: k = first-order rate constant, in hr^{-1}
 t = time, in hours
 C_o = starting concentration, in $\mu\text{g/L}$
 C_t = concentration at time t , in $\mu\text{g/L}$

Rate constants are calculated, using the concentrations shown in Table 4-7 (excepting those for P MW-1S). The calculated rate constants range between about 4×10^{-5} and $5 \times 10^{-5} \text{ hr}^{-1}$. If the relation shown by Henderson (1994) between k and pH is universal, the calculated rate constants for the Puchack Site data seem low, given the pH range, 4.43 to 6.28, observed in water from the wells listed in Table 4-7.

Because the observed decrease in chromium concentration over time could be a function both of geochemical interactions and of physical transport processes, it is difficult to assess the reason for the low calculated rate constants. It could be argued that, in the absence of any chemical reactions, the concentrations would have changed anyway because slugs of chromium-contaminated water are moving through the aquifers. The degree to which chemical reduction of chromium from groundwater takes place in the aquifers probably is a function of the amounts and types of materials that are electron-donors. Currently, no data giving detailed mineralogy of the soils or of the aquifer sediments in the study area are available. A determination of the reductive capacity of the aquifer sediments would provide a measure of the anticipated fate of chromium in the aquifer system.

The available data indicate that substantial amounts of Cr (VI) have been removed from surficial and near-surface soils, apparently by reduction and subsequent precipitation to solid phase Cr (III). It is more difficult, however, to identify the extent to which this process has taken place in the aquifers because of the confounding factor of physical transport. Because the decreases in chromium concentrations are similar (about 60 percent) in several wells that tap different parts of the chromium plumes, similar processes may be operating throughout the system.

5.1.2.4 Evidence for Natural Attenuation of Chromium in Groundwater

The total chromium concentration in a water sample collected early in May 1998 from well P MW-5I was $8,100 \mu\text{g/L}$, all of which was Cr (VI). In early September 2000, a second water sample was collected from P MW-5I; this sample contained $3,010 \mu\text{g/L}$ of total chromium, all of

which was Cr (VI). Over a period of 28 months, total chromium concentrations decreased by 63 percent. Similar decreases in total chromium concentrations were noted for samples from other wells (Table 4-7). In only two cases were the decrease in concentration relatively small. The decrease at Landfill 4 was only 15 percent, but the time between sampling rounds was only about 21 months. An 18 percent decrease was found at P MW-1S, with one of the longest times (33 months) between sampling rounds. P MW-1S taps water beneath a likely source; above-background concentrations of Cr (VI) are still present in soils at that location. It is likely that the smaller decrease in concentration over time at P MW-1S is the result of proximity to the source. At this location Cr (VI) has been supplied continually to the aquifer for a longer period of time than at any other downgradient location.

Although the data for wells at some locations clearly indicate that chromium concentrations are decreasing over time, the existing data that point conclusively to removal of chromium by interactions with other constituents are relatively few. The observation that total chromium concentrations on aquifer sediments tend to increase as the ratio of hexavalent to total chromium decreases indicates some removal of Cr (VI) and production of Cr (III). A decrease in pH from 5.3 to 4.6 at P MW-14 with the arrival of the chromium plume by 2001 also may point to redox reactions taking place. It is not clear whether the decreases in chromium are the result of reduction of Cr (VI) and precipitation of the resulting Cr (III), whether Cr (VI) is adsorbing to aquifer materials, or whether physical movement (advection and dispersion) and dilution of the plumes has led to decreases in concentration at a given well. Based on existing data, it is likely that all three processes have affected chromium concentrations. Nevertheless, until some measure of the aquifer sediments' capacity to reduce Cr (VI) is determined, it will be difficult to estimate how much chromium can be removed by natural processes, and how much needs to be removed by other means.

5.1.3 TRANSPORT OF CHROMIUM IN THE AQUIFER SYSTEM

Several issues need to be considered in any investigation of the transport of Cr (VI) in the Potomac-Raritan-Magothy aquifers. These are (1) the location of past surficial sources, (2) whether the sources are continuing to contribute chromium to the groundwater, (3) the direction of groundwater flow at the local scale, (4) the magnitude of vertical hydraulic gradients between aquifers, (5) the location of discontinuities in the confining units, and (6) the degree to which Cr (VI) is reduced by soils and aquifer materials to less mobile Cr (III). Following are discussions of these issues as they related to the historical and current transport of chromium.

5.1.3.1 Site Conceptual Model

Based on the information collected from the current and previous investigations, and the chemical and physical properties of chromium, a site conceptual model for the Puchack Site is formulated below. SGL Chrome may be a potential source of Puchack well field contamination. The site conceptual model will be further investigated in OU2.

Historical information indicates that SGL Chrome began operation in 1969. SGL Chrome purchased the property from Du-Mor Hard Chrome and consolidated Du-Mor with Modern Hard Chrome of Camden. Du-Mor purchased the property from Nenin H. McKay on January 21, 1963 (NJDEP 1990b). SGL Chrome was a nickel and chrome plating shop and generated over

9,000 gallons of plating wastewater per day, or 3.3 million gallons per year. It included three underground septic systems, two were used for discharging nickel and chromium wastes. Based on the nature of the operation and the investigation results, it is likely that significant portions of the chromium was introduced to the soils in the hexavalent form, which is highly soluble and can move easily through the environment.

Wastewater and chromium from the septic system moved down through the soil column and into the Middle aquifer (layers A-2a, A-2C1, and A-2b). Cr (VI) would first interact with constituents in the soil particles, whereby it would either be adsorbed onto the soil particles, and, where soils are noted to contain high levels of iron, the Cr (VI) would be reduced to Cr (III). When the reductive and adsorptive capacities of the soil were depleted, Cr (VI) would continue to migrate unimpeded, vertically and horizontally through the soil column or the aquifer. Chromium, together with the wastewater, flowed down into the Middle aquifer where further downward movement was impeded locally by a confining unit (layers A-2C1 in the Middle aquifer and C-2a separating the Middle aquifer and Intermediate Sand). Chromium contaminated groundwater migrated eastward until it encountered discontinuities in confining layer C-2a. Under a downward hydraulic gradient, chromium contaminated groundwater then moved downward to the Intermediate Sand (layer C-2AI) in the vicinity of well clusters P MW-26 and P MW-27. In the Intermediate Sand, chromium contaminated groundwater apparently was drawn east-northeastward toward Puchack well field, when it was in operation, and also moved downward through discontinuities in confining unit C-2b in the vicinity of well cluster P MW-15 to the Lower aquifer, where chromium contaminated groundwater was also drawn toward the Puchack well field. This hypothesis is supported by the chromium contamination observed in the Intermediate Sand and Lower aquifer at and near the well field. The hydrostratigraphy of the site, including the area around SGL and well clusters P MW-26 and P MW-27, is discussed in more detail in Subsection 3.5.2.1.

The discharge from SGL Chrome began in 1969 and terminated in 1981. So over this 12 year period, an estimated 39 million gallons of wastewater (9,000 gallons per day x 365 days/year x 12 years) was discharged into the ground (NJDEP 1990b). Given that Du-Mor Hard Chrome purchased the facility in January 1963, an additional unknown quantity of wastewater could have discharged into the ground since 1963. Chromium contamination was detected in Puchack 4R/6-70 in the early 1970s. Sulfate, as known to be in the SGL discharge, greatly increases chromium mobility in groundwater as discussed in Subsection 5.1.1.2. The distance between SGL Chrome and Puchack 4R/6-70 is approximately 3,000 feet. Therefore, the chromium contaminated groundwater was traveling at between several hundred to a thousand feet per year.

Several factors could contribute to this high migration velocity: groundwater velocity was much higher when Puchack wells were pumping at full capacity; the large quantity of waste water quickly depleted the adsorptive and reductive capacities of the soil particles; the discharge created a higher hydraulic gradient; sulfate (known to be in the SGL discharge) greatly increases chromium mobility in groundwater; and portions of the contaminated groundwater could conceivably have migrated through preferential channels in the aquifer.

General use of the Puchack well field was terminated in 1984. However, controlled pumping of well Puchack 1 continued until 1998. Groundwater flow was toward the well field (east-northeast) at the Puchack Site while the well field was in full operation. The groundwater now

flows toward the southeast, since the termination of pumping at the well field. Because of the change in groundwater flow direction, the chromium plumes in the various aquifers have moved towards the southeast as a slug (advective transport), and because of the adsorption property of the soil particles, residual chromium levels in groundwater (at or near the MCL) were left in the vicinity of the Puchack well field. The residual contamination in water tapped by the Intermediate Sand wells P MW-17I (100 µg/L) and CC MW-4I (23.2 µg/L) illustrates this condition.

At the Puchack Site, the current spatial extent of chromium-contaminated parts of the Middle aquifer, Intermediate Sand, and Lower aquifer differ widely (see Figure 5-5). Overall, most of the highest concentrations of chromium currently measured are in the plume in the Intermediate Sand. In the Intermediate Sand, the highest chromium concentrations are in the middle of the plume, in the vicinity of wells CC MW-2A, P MW-5I, and P MW-25I. In the Lower aquifer the highest concentrations tend to be in the upper zone of the aquifer (A-3a), and lower concentrations tend to be in the lower zone (A-3c), which is consistent with the rapid, nearly horizontal flow in this aquifer. In the Middle aquifer, the discrete area of chromium-contaminated groundwater tapped by well P MW-1S contains the highest chromium concentrations measured in any of the aquifers. High concentrations of chromium were also found in soil at the SGL Chrome property; therefore, both the soil and groundwater are likely acting as a continuing source for groundwater contamination locally. It is not known whether chromium contaminated water in the Middle aquifer at the SGL Chrome property still contributes to the plumes of chromium contaminated water in the Intermediate Sand and Lower aquifer or if it is now cut off as a result of changes in local pumping regimes.

A downward vertical gradient provided by pumping from the Puchack well field and other nearby well fields drawing from the Lower aquifer provided the driving force for contaminant migration from the Middle aquifer to the Intermediate Sand, and subsequently Lower aquifer (Figure 5-6). The Intermediate Sand also is connected hydraulically to the Lower aquifer (Walker and Jacobsen, in press) and thus this condition has, in the past, facilitated the movement of contaminated water downward into the more regionally extensive Lower aquifer. The hydraulic gradient between the Intermediate Sand and the Lower aquifer probably has decreased since cessation of full-scale pumping at the Puchack well field, to the point where, since 1998, heads in both units are nearly the same. The similar heads illustrate the effective hydraulic connection between these two water-bearing zones. Thus, there is currently little impetus for contamination to continue to move downward, out of the Intermediate Sand. This could change if local pumping patterns in the Lower aquifer change.

5.1.3.2 Current Transport of Chromium

Pumping at the Puchack well field has ceased, and the local flow in all aquifers is generally toward the southeast, in the direction of regional groundwater flow. The Puchack plume has likewise been moving away from the Puchack well field, along the regional flow direction to the southeast. This is evidenced in the sample results taken in 1997-1998, and 2000-2001. Future plume movement will depend on the groundwater, geochemical and retardation factors, as well as on possible remedial action. The U.S. EPA is conducting a treatability study to evaluate the feasibility of treating chromium contaminated groundwater in-situ.

The conductivity (K) for the Intermediate Sand aquifer estimated at 150 feet per day, based on USGS modeling results for the Puchack Site. Assuming an overall porosity of 0.3 in the Intermediate Sand and a hydraulic gradient of 0.0017 feet/foot (based on April 2001 groundwater level measurements), the groundwater velocity at the Puchack Site would be approximately 10 feet per year (ft/yr). Based on the retardation factors calculated previously (ranged from 4 to 717 for hexavalent and 6 to 1,402 for total chromium within the plume area), the Cr (VI) plume would travel from approximately 0.4 to 78 ft/yr, and the total chromium plume would travel from 0.2 to 52 ft/yr. During the 34 months between sampling rounds, the Cr (VI) plume could have moved on the order of a few feet to 156 feet. At the fringe area of the plume, the retardation factor is over 46,000, implying the Cr (III) would hardly move. Therefore, for the Cr (VI) plume to move beyond the current boundary, it must first overcome the reductive capacity of the soils particles.

5.2 ORGANIC CONTAMINANTS

A wide variety of VOCs are found in groundwater in the study area; the most prevalent are halogenated aliphatic compounds, principally chlorinated solvents such as PCE, TCE, and 1,1,1-TCA; aromatic compounds, some of which may be gasoline-related, occur at considerably lower frequency. Of the BTEX compounds, toluene occurs only in trace amounts in samples from several wells, but other aromatics occur at high concentrations. The variety of compounds and their scattered distribution is indicative, in part, of multiple sources, and in part, of degradation processes.

5.2.1 REACTIONS INVOLVING VOLATILE ORGANIC COMPOUNDS IN GROUNDWATER

Microbial degradation of aromatic hydrocarbons such as the BTEX compounds can occur under aerobic and anaerobic conditions. Rapid biodegradation (oxidation) takes place in aerobic environments where these compounds are used by microbes as the primary electron donors. The supply of oxygen tends to be rate limiting rather than a lack of nutrients such as phosphorus and nitrogen (Wiedenerier et al. 1998). For oxidation of BTEX to occur in the absence of molecular oxygen, the microbial oxidation of organic carbon is carried out using other terminal electron acceptors that include Fe (III), manganese (IV), nitrate, and sulfate (Wiedemeier et al. 1998); the oxygen incorporated into the ring structure during degradation may come from water (Chapelle 1993).

Both benzene and toluene have been shown to degrade by more than one pathway, and thus intermediate compounds can vary. Intermediate degradation products formed by ring oxidation under anaerobic conditions are phenol (from benzene) and cresol (from toluene). In both cases, the ultimate degradation product is carbon dioxide (CO₂). Field and laboratory experiments show that degradation of BTEX generally occurs quickly, in months to a few years, although ethylbenzene appears to persist under anaerobic conditions (Chapelle 1993).

Halogenated aliphatic hydrocarbons also undergo degradation under aerobic and anaerobic conditions. Because the highly halogenated compounds are already oxidized, the more highly halogenated the compound is (such as PCE, with four Chlorine atoms), the more resistant it is likely to be to aerobic biodegradation (Wiedemeier et al. 1998). Degradation of these compounds

typically occurs in an anaerobic environment by reduction reactions. These reactions are mediated by microbes, which use the halogenated compound as an electron acceptor rather than as a source of carbon. Therefore, a source of carbon, such as naturally occurring organic matter or the products of other already degraded hydrocarbons, is needed for the microbial metabolism (Wiedemeier et al. 1998).

Highly chlorinated compounds, such as PCE, TCE, and 1,1,1-TCA, are progressively dechlorinated in a process known as hydrogenolysis, although most groundwater systems lack sufficient electron donors to promote complete reductive dechlorination of the highly chlorinated compounds (Chapelle 1993). During hydrogenolysis, the chlorine atoms are replaced by hydrogen, resulting in compounds with reduced carbon and less chlorine. Thus, PCE degrades to TCE, and TCE degrades to dichloroethylene (DCE), with the *cis* isomer (*cis*-1,2-DCE) predominant over the *trans* isomer. As reductive dechlorination proceeds, vinyl chloride is produced, and ultimately, ethylene (Chapelle 1993; Wiedemeier et al. 1998).

A similar sequence of reactions degrades 1,1,1-TCA, which has also been shown to be abiotically degraded. In abiotic degradation, 1,1,1-TCA is reductively dehalogenated to the daughter product chloroethane, which can further react to produce vinyl chloride by dehydrohalogenation (removal of a chlorine atom from one carbon atom and subsequent removal of a hydrogen atom from an adjacent carbon atom). The daughter product chloroethane also can react with water, whereby a chlorine atom is replaced with a hydroxyl ion (hydrolysis) to produce ethanol (Wiedemeier et al. 1998). 1,1,2,2-tetrachloroethane degrades to produce 1,1,2-TCA and TCE.

Cometabolism is another process by which chlorinated solvent can be degraded. Enzymes that are produced by various microbes for other purposes catalyze the degradation. This type of degradation is documented for aerobic environments, and, with the exception of PCE, may be the only way that the highly chlorinated solvents are degraded in such environments (Wiedemeier et al. 1998).

Both the chlorinated solvent and the aromatic hydrocarbons in the dissolved phase also can be removed from solution by adsorbing to particles in the aquifer matrix. The most common adsorption mechanism for these compounds is hydrophobic bonding. This occurs because the water molecule is more polar than the particle surfaces, and so the non polar organic molecules tend to leave the aqueous phase and adsorb to the particles (Wiedemeier et al. 1998). Because adsorption typically is reversible, the aquifer matrix may not permanently sequester compounds, but may release the organic contaminants as solution concentrations decrease. The net result of adsorption is to retard the advance of the organic contaminant(s) through the aquifer.

The retardation factors are calculated using the following equation:

$$R=1+P_b *K_{OC} *f_{OC}/n$$

where: R is the retardation factor

P_b is the bulk density of sediment at 1.5 g/ml (EPA 1996)

K_{OC} is the calculated organic carbon soil water partition coefficient in ml/g

n is the porosity of the aquifer at 0.3

f_{OC} is organic carbon fraction at 0.003

The retardation factor for the volatile organic compounds are calculated in the following table.

Compound	K_{OC}^*	R
PCE	155	3
TCE	166	3
1,1,1-TCA	110	3
Benzene	58.9	2
Toluene	182	4
Ethylbenzene	363	6
m-xylene	407	7
o-xylene	363	6
p-xylene	389	7

* K_{OC} source: Table C-1 in USEPA 1996

5.2.2 FATE OF VOLATILE ORGANIC COMPOUNDS IN GROUNDWATER

The fate of organic contaminants in groundwater depends on their interactions, not only with other chemical constituents, but also with microbes in the aquifer. As with inorganic contaminants, a decrease in concentrations of dissolved organic contaminants in groundwater at a specific location over time can be the result of chemical, in this case, biogeochemical, interactions, or could indicate that the plume of contaminated water has moved to another location. Currently, the investigations into VOC contamination of groundwater in the Puchack Site indicate that there have been decreases in concentrations of VOCs at some location over time, and there is evidence for degradation of some compounds.

5.2.2.1 Changes in Concentrations of Volatile Organic Compounds

In general, VOC concentrations in groundwater samples collected in 1999-2001 were lower than those in samples collected from the same wells in 1997-1998. However, the changes in most

VOC concentrations over time were not great (Table 4-8). In some cases, changes in concentrations with time may be the result of a shift in the position(s) of the VOC plume(s) or changes in inputs from the sources. The changes may be the result of degradation or adsorption of organic compounds. Increases in concentration over time are likely due to movement of the plumes, whereas decreases over time could indicate both plume movement and degradation of the compounds. The presence or increase in daughter products indicate compound degradation. Changes in the concentrations of other constituents and anomalies in redox potential may also indicate degradation of VOCs.

The most substantial changes in concentrations over time were noted for aromatic compounds (Table 4-8). Concentrations of TCE and PCE also decreased with time in most of the samples from wells which were sampled in 1998 and 2000-2001. Concentrations of PCE and TCE increased slightly at a few locations in wells sampled over this period. Because aromatic compounds degrade faster than chlorinated solvent, the concentrations of aromatic compounds should decrease faster, over time, than the concentrations of chlorinated compounds. Adsorption to the aquifer matrix may also account for some of the decrease in the concentration of both chlorinated compounds and aromatic hydrocarbons.

5.2.2.2 The Geochemical Environments of Groundwater Containing Volatile Organic Compounds

The geochemical environments of the groundwater in which the most abundant VOCs (PCE and TCE) are detected vary with respect to several characteristics and constituents. Relatively low to moderate (<50 µg/L) TCE concentrations occur in water with a wide range of oxidation/reduction potential (ORP) values and concentrations of DO. At high TCE concentrations, both ORP and DO concentrations tend to increase as TCE concentration increases. Thus, the highest concentrations of TCE tend to occur in the more oxic parts of the aquifer system. Some of this distribution is the result of physical transport, with higher concentrations closer to sources and therefore in more oxic parts of the system. Some of this may be a reflection of more reducing conditions that promote reductive dechlorination resulting in lower concentrations where TCE concentrations are high, which could indicate that larger concentrations of degradation products such as cis-1,2-DCE are generated when larger concentrations of a parent compound such as TCE are present.

Given that most of the higher TCE concentrations occur in more oxic parts of the aquifer system, iron concentrations tend to be low when TCE concentrations are high. Sulfide, which could act as an electron donor in a more reducing environment, is not likely to be present in oxic parts of the system. The highest TCE concentrations tend to be associated with relatively low alkalinity concentrations, which may be indicative of little microbial activity.

The DO levels in water containing aromatics (principally BTEX) typically were low (<1 mg/L); these areas are present in near surface water bearing zones, where conditions typically are oxic. Thus, a geochemical environment conducive to anaerobic degradation of these aromatic compounds appears to be present where they are detected, indicating microbial activity. The lowest Eh (-125 mV) encountered during the study was measured at well P MW-10M, indicating that biodegradation of the organic compounds, predominantly benzene, was actively occurring. The highest aromatic hydrocarbon concentrations were found in samples from the Middle

aquifer, and the lowest in samples from the Lower aquifer. This could indicate that substantial degradation had taken place during the time in which these compounds moved down to the Lower aquifer.

Low dissolved-oxygen levels are not confined to BTEX-contaminated groundwater, however; oxygen concentrations tend to decrease with depth in the aquifer system. Only one of the samples from the 19 wells finished in A-3c (the lower layer of the Lower aquifer) yielded water with $\text{DO} > 2 \text{ mg/L}$. Consequently, the geochemical environment of the Lower aquifer generally appears to be more conducive to anaerobic degradation of a variety of VOCs than do the geochemical environments present in parts of the shallower aquifers. The detections of vinyl chloride in Lower aquifer wells, but not elsewhere, may indicate that reductive dechlorination processes are most favored by the geochemical environment of the Lower aquifer. Insofar as vinyl chloride degradation is favored by an aerobic environment (Wiedemeier et al. 1998), there remains the potential for a buildup of vinyl chloride as a degradation product in Lower aquifer, where it may not be degraded further.

5.2.2.3 Evidence for Natural Attenuation of Volatile Organic Compounds in Groundwater

A decline in concentrations of various aromatic compounds (mostly BTEX) in groundwater with time, coupled with the appropriate geochemical environment for degradation to occur, is indicative of natural attenuation of these compounds. For example, concentrations of benzene decreased substantially in three years, from 1,200 to 170 $\mu\text{g/L}$, in samples from a Middle aquifer well (P MW-10M). In the same well, ethylbenzene concentrations decreased similarly; from 1,000 to 190 $\mu\text{g/L}$, and xylene concentrations decreased from 2,100 to 230 $\mu\text{g/L}$. Toluene was not detected in the sample (the detection limit was 100 $\mu\text{g/L}$, higher than normal, because the sample was diluted). As discussed above, the Eh (-128 mV) measured in a sample from this well reflected a localized reducing geochemical environment, which could indicate biodegradation of BTEX compounds was occurring. High alkalinity (222.9 mg/L as CaCO_3) in this sample supports the inference of active biodegradation.

TCE is the primary organic contaminant in groundwater at the Puchack Site. However, PCE was also detected frequently. Some of the TCE may be the product of reductive dechlorination of PCE. However, because TCE is common, either alone or in combination with other chemicals, in industrial, commercial, and household applications, much of the TCE detected in the soils and aquifer system probably originated as TCE and did not result from degradation of PCE. Nevertheless, in the samples from Middle aquifer well P MW-1S collected in 1998 and 2001, concentrations of PCE decreased over time as concentrations of TCE increased (Table 4-8). This may be an example of reductive dechlorination, as DO concentrations were negligible in 1998 (0.6 mg/L). A DO concentration of 3.48 mg/L was measured in 2001; however, this higher value may be a sampling artifact. Consequently, it is not possible to determine whether the present geochemical environment of the water tapped by P MW-1S is conducive to reductive dechlorination.

Low ($< 4 \text{ } \mu\text{g/L}$) concentrations of cis-1,2-DCE were detected in only a few other Middle aquifer wells; larger concentrations (up to 16 $\mu\text{g/L}$) were detected with greater frequency in Intermediate Sand wells, and the largest concentrations (up to 36 $\mu\text{g/L}$) were measured in Lower aquifer wells. Increasing concentrations of cis-1,2-DCE with depth appear to indicate that reductive

dechlorination has taken place along the paths the organic contaminants have followed, with the deepest, and presumably oldest, water containing the largest concentrations of degradation products. Vinyl chloride only was detected in water samples from four Lower aquifer wells, indicating a more fully developed dechlorination process in the Lower aquifer.

Dechlorination should result in a decrease in concentrations of the chlorinated compound and an increase in chloride concentrations in the groundwater, but, using data for all wells sampled in 2000-2001, relations between concentrations of TCE or PCE and chloride were not apparent. The lack of relations probably is the result of inputs of chloride ion derived from other sources such as road salt, or, possibly, various industrial effluents, that overwhelm the amount of chloride that would be released by reductive dechlorination.

The compound 1,1,1-TCA, although not as ubiquitous as TCE, occurs in high concentrations in water samples from several shallow wells (GSM MW-1, P MW-12S, P MW-29S, and P MW-30S). Concentrations of 1,1,1-TCA detected in the Intermediate Sand and Lower aquifer are below the MCL. This distribution of concentrations would seem to indicate that 1,1,1-TCA is being degraded relatively quickly, unlike TCE. Reaction rates reported by Wiedemeier et al. (1998) indicate that this is plausible. Scattered detections of low concentrations of 1,2-DCA may indicate that aerobic degradation of 1,1,1-TCA has taken place. Chloroethane, another degradation byproduct of 1,1,1-TCA, has not been detected. Concentrations of other highly chlorinated ethanes, 1,1,2,2-tetrachloroethane and 1,1,2-TCA, are either not detected or at negligible concentrations in groundwater of the study area; thus, abiotic degradation of 1,1,2,2-tetrachloroethane apparently is not an important process at this site, owing to its seemingly low initial incidence.

Evidence of degradation of chlorinated solvents by cometabolism reactions is not apparent. Some of the aerobic bacteria known to participate in such processes, such as ethene oxidizers and ammonia oxidizers, could be present in groundwater of the study area. Nevertheless, because rates of cometabolism are slow (Wiedemeier et al. 1998), the field data are unlikely to reveal whether these processes are occurring.

5.2.3 TRANSPORT OF VOLATILE ORGANIC COMPOUNDS IN THE AQUIFER SYSTEM

As with the transport of chromium, the issues that relate to the movement of VOCs through the Potomac-Raritan Magothy aquifer system include:

1. The location of past surficial sources
2. Whether the sources are continuing to contribute VOCs to the groundwater
3. The groundwater flow direction at the local scale
4. The magnitude of the vertical hydraulic gradients between aquifers
5. The location of discontinuities in the confining units
6. The degree to which VOCs are attenuated by aquifer media or are degraded by chemical and biological processes

There is limited information regarding the sources of VOCs, but generalized source areas and pathways through confining units can be deduced from the current distribution of VOCs in the

aquifer system. There also is evidence of processes that are causing degradation of VOCs, as discussed above.

5.2.3.1 Contributions from Sources of Volatile Organic Compounds

The sources of VOC contamination at the Puchack Site appear to be more numerous and more scattered than the chromium sources because there are more places where VOCs are present in saturated parts of the Upper and Middle aquifers than places where elevated concentrations of chromium are present. The potential VOC source areas are listed in Subsection 4.5.7. Although preliminary investigations of several possible sources have taken place, there may be VOC sources that have not been identified. Whether the sources are still contributing VOCs to groundwater is also not clear.

5.2.3.2 Historical Transport Mechanism of Organic Contaminants

As with the chromium contamination, the sampling of well clusters, with wells finished in different aquifer units, gives insight into the migration of organic contaminants. VOC contaminated water appears to have moved from the Middle aquifer, through breaches in confining units, into the Intermediate Sand and Lower aquifer over a wider area than has chromium-contaminated water. VOCs generally do not appear to have reached the Lower aquifer in the western part of the study area, but they appear with greater frequency, at increasingly deeper depths, and in higher concentrations in more easterly parts of the aquifer system (Figures 4-18 through 4-20).

VOCs from surface sources may or may not be transported to deeper water-bearing zones, depending upon the effectiveness of confining units in preventing the passage of contaminated water. In the western and central parts of the Puchack Site, groundwater samples from Middle aquifer monitoring wells P MW-1S, CCMW-1B, P MW-16M, and P MW-27M, show high concentrations of one or more VOCs, indicating the wells are probably near a source or sources. Intermediate Sand wells that tap VOC-contaminated water at the same locations include P MW-16I and P MW-27I.

Driller's logs indicate that, at the P MW-16 well cluster, except for (unsaturated) clays to about 40 feet, the sediments down to about 150 feet are mostly sands, with minor clay lenses, an apparent result of cut and fill. Although there are more clay lenses at the P MW-27 cluster, the system at this location also contains areas of cut and fill. Consequently, VOCs have likely descended from the Middle aquifer into the Intermediate Sand at or near these locations, driven by the downward head gradient that existed (and still exists) between the Middle aquifer and the Intermediate Sand. At the P MW-14 group of wells, VOC-contaminated water is present in the Intermediate Sand, and small concentrations of VOCs also are present in the Lower aquifer. There is no Middle aquifer well at this location, so whether the distribution of VOCs locally is the result of vertical or lateral movement, or a combination of both, currently is not known. In the northeastern part of the study area, which is off the Puchack Site, Upper and Middle aquifer wells tapping VOC-contaminated water include GSM MW-1, P MW-21S, and P MW-31M. Intermediate Sand wells that also tap VOC-contaminated water at the same locations are P MW-21I and P MW-31I. The sediments at the P MW-21 cluster are variable with depth; other

than thin clay lenses, the only substantial clay layer (C-2b) encountered is from 112 to 122 feet depth. Clay layer (C-2a) apparently is ineffective as a confining unit upgradient or in the vicinity of P MW-21I; lateral transport may be partly or mostly responsible for the VOC contamination at P MW-31I. There apparently are breaches in the clay layer C-2a, and downward head gradients have allowed the contamination to move down from the Middle aquifer.

In the southeastern part of the study area, which is also off the Puchack Site, the Middle aquifer wells Bell-1, P MW-12S, and P MW-29S tap VOC-contaminated water. No well cluster is present at Bell-1, but Intermediate Sand and Lower aquifer wells at the P MW-12 and P MW-29 clusters also tap VOC-contaminated water, and, in both cases, concentrations of TCE increase with depth. Intermediate Sand well P MW-30I taps VOC-contaminated water, although nearby P MW-13I does not. Lower aquifer well P MW-13D taps VOC-contaminated water, but the sample from P MW-30D (which is deeper than 13D) contained only a trace of PCE. In the sample from well P MW-35I in layer A-3a of the Lower aquifer, the concentration of TCE (360 µg/L) is very high, but in the sample from P MW-35D, in layer A-3c, the concentration was only 2.5 µg/L.

It is not possible, currently, to determine whether the high concentrations of VOCs (particularly TCE) in the upper part of the Lower aquifer are the result of the vertical movement of contaminated water, or whether the lateral movement of a plume from upgradient areas has mostly contributed to the high concentrations. Given the generally sub-horizontal orientation of flow in the Lower aquifer, a significant contribution to the TCE concentrations in the eastern part of the study area are likely from upgradient areas in the Lower aquifer.

5.2.3.3 Current Transport Mechanism for Volatile Organic Compounds

The local and regional direction of groundwater flow generally is toward the southeast in all the aquifer units now that pumping at the Puchack well field has ceased; therefore, the contaminant plumes now are likely to move in a generally southeasterly direction. Groundwater at the Puchack Site is estimated to be moving at about 310 ft/yr as calculated in Section 5.1.3.2. The VOCs are therefore estimated to be moving from 44 ft/yr for m-xylene and p- xylene to 155 ft/yr for benzene using the retardation factors previously calculated.

As is the case with the movement of chromium-contaminated groundwater, factors that affect the transport of VOC contaminants can be summarized as: breaches in confining units, hydraulic head gradients, and the geochemical processes that cause the movement of contaminants to be retarded. The occurrences of VOC contamination throughout the aquifer system at the Puchack Site indicate that the head differences have been, and in some cases still are, sufficient to drive contaminated water from shallow water-bearing zones to deeper ones through breaches in the confining units. The widespread occurrences of VOCs in deeper water-bearing zones indicate that breaches in confining units also are widespread. The presence of the breaches, many of which appear to be in filled channels in the various layers of the aquifer system, indicates that the concept of confining units acting as barriers to contaminant movement is not applicable to parts of the aquifer system in the study area. The tops of the subsurface layers are erosional surfaces, and within each layer, there are undoubtedly other erosional features that may be intersected by the wells drilled at the Puchack Site. Some of these features provide conduits for contaminated water to move between layers.

5.3 INTERACTIONS BETWEEN INORGANIC AND ORGANIC CONTAMINANTS

The plumes of chromium-contaminated and VOC-contaminated water at the Puchack Site overlap to a small extent in the Middle aquifer because the chromium plumes, as currently delineated in the Middle aquifer, are small. The overlap of the two plumes is much greater in both the Intermediate Sand and the Lower aquifer. Where the inorganic and VOC plumes intersect or overlap, there is the potential for interactions between contaminants or competition between contaminants.

TCE is the most common organic contaminant in and on the fringes of the chromium plumes, occurring at detectable levels in nearly all the samples containing chromium at concentrations $>10\text{ }\mu\text{g/L}$. With the exception of the sample from well P MW-1S, completed in the Middle aquifer, TCE concentrations associated with the chromium plumes were less than $55\text{ }\mu\text{g/L}$. In the sample from P MW-1S, the TCE concentration was $110\text{ }\mu\text{g/L}$, up from the $76\text{ }\mu\text{g/L}$ measured in 1998 (Walker and Jacobsen, in press). As discussed earlier, PCE concentrations, which were high in 1998 ($280\text{ }\mu\text{g/L}$) had decreased by 2001, indicating that degradation had taken place. The chromium concentrations in water from P MW-1S decreased little, relative to decreases over time seen in samples from other wells. P MW-1S is screened in the first water-bearing zone beneath a probable chromium and VOC source. Consequently, it is not possible to assess whether degradation of the VOCs has inhibited reduction of Cr (VI) and subsequent precipitation of Cr (III) compounds, or the reverse, because both Cr (VI) and VOCs are present in the soils above. The soils may still be contributing these contaminants to the shallow groundwater.

Elsewhere in the chromium plumes, VOC concentrations are substantially less than chromium concentrations. Even though the chromium concentrations have decreased over time, they still overwhelm the VOC concentrations within the chromium plume areas. Therefore, the VOCs are unlikely to interfere with chemical reactions involving the chromium at present. Perhaps when chromium levels have decreased still further, competition between inorganic and organic contaminants for electron donors may become an important factor in the attenuation of the contaminants.

6.0 HUMAN HEALTH RISK ASSESSMENT

This section has been omitted from this document. It has been submitted under separate cover.

7.0 SUMMARY AND CONCLUSIONS

This section provides a summary of the major findings of the RI. The conclusions drawn from the various investigations, which were conducted to determine the nature and extent of groundwater contamination and potential source areas, are discussed below. A draft baseline human health risk assessment has been submitted separately and will be incorporated into the Final RI report.

Groundwater quality in the Potomac-Raritan-Magothy aquifer system in Pennsauken Township has been affected by both inorganic and organic contaminants. Stratigraphic and hydrologic data gathered at newly installed monitoring wells has led to refined interpretations of local hydrostratigraphy, groundwater flow directions, and hydraulic gradients. The distribution of contaminants in the aquifer system can be better understood in light of these interpretations. Results of the present investigation include the following significant findings.

7.1 HYDROGEOLOGY

- There are four water-bearing units: the Upper aquifer (mostly unsaturated in the study area), the Middle aquifer, the Intermediate Sand, and the Lower aquifer, all separated by leaky confining units.
- A detailed delineation of the hydrostratigraphic framework in the study area indicates that there are areas of cut-and-fill in the confining units. These create permeable zones that apparently do not prevent passage of water through the confining units.
- There are downward head gradients between the Middle aquifer and Intermediate Sand that promote movement of contaminated water between these two water bearing units.
- Although hydraulic heads between the Intermediate Sand and the Lower aquifer are now similar, it is likely that during full-scale pumping at the Puchack well field, a greater downward head gradient between these two units existed. These conditions probably contributed to the movement of chromium contamination out of the Intermediate Sand into the Lower aquifer and to the Puchack wells.
- During full-scale pumping at the Puchack well field, groundwater flow directions, locally, were probably toward the northeast, but now have shifted to the southeast.
- A general increase in water level elevations of over 2 feet in all aquifers from 1998 to 2000 was observed.

7.2 NATURE AND EXTENT OF CONTAMINATION

7.2.1 INORGANIC CONTAMINATION IN GROUNDWATER

Hexavalent chromium contamination is the primary concern at the Puchack Site. There also are scattered instances of mercury with no apparent pattern, which may be derived from aquifer materials. The major findings of chromium contamination are:

- Chromium-contaminated groundwater forms plumes in each of three water bearing zones: the Middle aquifer, the Intermediate Sand, and the Lower aquifer.
- The position and orientation of the chromium plumes indicate there are at least two chromium contaminant sources, of which one appears to be unrelated to the Puchack Site.
- Chromium-contaminated groundwater has moved through breaches in confining units between the water-bearing zones in response to downward vertical head gradients, resulting in contamination reaching deeper water bearing units.
- The plumes in the Intermediate Sand and Lower aquifer are moving to the southeast, an apparent shift in direction since shut down of the Puchack well field.
- Chromium concentrations in the groundwater plumes appear to have decreased from 1997-1998 to 2000-2001.

7.2.2 ORGANIC CONTAMINATION IN GROUNDWATER

- The most frequently detected volatile organic contaminant is TCE; others, including PCE, 1,1,1-TCA, and BTEX, are detected less frequently.
- VOC contamination is more widespread in all water-bearing units than chromium contamination. Coherent VOC plumes have not been identified.
- Based on the variety of compounds and widespread distribution, multiple sources of VOCs are likely.
- At several locations VOC concentrations have declined and there is evidence of degradation of the VOCs, particularly the chlorinated compounds, as cis- 1,2-DCE and vinyl chloride are detected, and their frequency and concentrations increase with depth in the aquifer system.
- As with the chromium plumes, there is evidence of movement of VOC contamination.

VOC contamination is a secondary concern at the Puchack Site. Remediation of associated, commingled VOC contamination is a secondary goal for remediation. EPA intends to include treatment of VOCs that are encountered during Puchack chromium plume capture. VOC contamination that is not captured within the chromium plumes will be considered separately from the Puchack remediation.

7.2.3 POTENTIAL CONTAMINATION SOURCES

Limited investigations were conducted at five potential source areas. The major findings are:

- The SGL Chrome property appears to be a source of chromium contamination, based on the high concentrations of chromium detected in soil and groundwater samples.
- Only sporadic chromium contamination, mostly at levels below background concentrations, were detected in samples from the four other properties investigated.

- Organic contamination was found in all five properties. The major contaminants include TCE, 1,1,1-TCA, and PCE.
- High concentrations of 1,1,1-TCA were detected in soil gas and soil samples from the Supertire property.

7.3 CONCLUSIONS

On the basis of data from this and previous investigations in the study area, the following conclusions can be drawn.

- Chromium-contaminated groundwater forms plumes in the Middle aquifer, Intermediate Sand, and Lower aquifer.
- Residual chromium contamination exists in soils and sediments overlying the Middle aquifer. This contamination may represent a continuing source of chromium to the aquifer system.
- The SGL Chrome property appears to be a source of chromium contamination for the Puchack well field, based on the high concentrations of chromium detected in soil and groundwater samples.
- Chromium and VOC contamination are commingled within the areas of the chromium plumes and VOC sources may or may not be associated with the sources of the chromium.
- The detailed delineation of the hydrostratigraphic framework has confirmed there are permeable parts of the confining units that are the result of a complex depositional and erosional geologic history. As a result, both inorganic and organic contaminants are able to migrate downward at certain locations.
- Groundwater flow directions have shifted from northeast to southeast, resulting from shut down of the Puchack well field.

7.4 RECOMMENDATIONS

The following data gaps have been identified and should be considered in planning future work:

- Although a likely source of chromium contamination in the Middle aquifer has been identified, the current extent of chromium contamination in the Middle aquifer has not been conclusively determined. Consequently, all the potential sources of the chromium contamination that has reached the Intermediate Sand and the Lower aquifer may not have been identified.
- The extent of the VOC contamination in the study area soils and sediments has not been fully investigated, although some potential sources have been identified.
- Chromium concentrations appear to be decreasing in some portions of the plume, which requires further investigation.

EPA plans to conduct OU 2 investigations for the chromium source areas, which will provide answers to the data gaps identified above. EPA also plans to conduct treatability studies to formulate a cost effective remedy for the chromium plume.

8.0 REFERENCES

- Barringer, J. L.; Szabo, Z., and Barringer, T. H. 1998. Arsenic and Metals in Soils in the Vicinity of the Imperial Oil Company Superfund Site, Marlboro Township, Monmouth County, New Jersey. U.S. Geological Survey Water-Resources Investigations Report. 98-4016: 251.
- Bartlett, R. J., 1991, Chromium cycling in soils and water: Links, gaps, and methods: *Environmental Health Perspectives*, v. 92, p. 17-24.
- Buerge, I. J. and Hug, S. J. 1999. Influence of Mineral Surfaces on Chromium (VI) Reduction by Iron (II). *Environmental Science and Technology*. 33(23): 4285- 4291.
- CDM. 1986. Summary of Conclusions and Recommendations of Chromium Contamination Analyses at Puchack Well Field. Edison, NJ: Camp Dresser and McKee, Inc. Report prepared for the New Jersey Department of Environmental Protection.
- _____. 2000a. Final RI/FS Work Plan for the Puchack Well Field Superfund Site, Phase I RI/FS, Pennsauken, New Jersey. Volume I. New York, NY: CDM Federal Programs Corporation, May 18, 2000.
- _____. 2000b. Final Quality Assurance Project Plan for the Puchack Well Field Superfund Site, Phase I RI/FS, Pennsauken, New Jersey. New York, NY: CDM Federal Programs Corporation, June 2, 2000.
- _____. 2000c. Addendum to the Final RI/FS Quality Assurance Project Plan for the Puchack Well Field Superfund Site. Pennsauken, New Jersey. New York, NY: CDM Federal Programs Corporation.
- _____. 2001a. ERT Soil Boring and Monitoring Well Soil Sample Data, Puchack Well Field Superfund Site Remedial Investigation/Feasibility Study (RI/FS), Pennsauken Township, New Jersey. New York, NY: CDM Federal Programs Corporation.
- _____. 2001b. Draft ERT Soil Boring Report, Puchack Well Field Superfund Site Remedial Investigation/Feasibility Study (RI/FS). Pennsauken Township, New Jersey. New York, NY: CDM Federal Programs Corporation.
- _____. 2001c. Groundwater Sample Data, August 2000-April 2001, Puchack Well Field Superfund Site Remedial Investigation/Feasibility Study (RI/FS), Pennsauken Township, New Jersey. New York, NY: CDM Federal Programs Corporation.
- Chapelle, F. H. 1993. *Ground-Water Microbiology and Geochemistry*. New York: John Wiley and Sons, Inc.
- Davis, A., and Olsen, R. L. 1995, The geochemistry of chromium migration and remediation in the subsurface: *Ground Water*. V. 33, no. 5, p. 759-768.

Dooley, J. H. 1998. Comprehensive Chemistry of Select Greensand from the New Jersey Coastal Plain. In: *New Jersey Geological Survey Technical Memorandum*, 98- 1:20. Trenton, New Jersey: Department of Environmental Protection.

Eary, L. E., Rai, D., 1988, Chromate removal from aqueous wastes by reduction with ferrous iron: *Environmental Science and Technology*, v. 22, no. 8, p. 972-977.

Enviro-Sciences, Inc. 1990. Environmental/Historical Investigation, 7200 Westfield Avenue, Pennsauken Township, Camden County, New Jersey. Mt. Arlington, New Jersey: Enviro-Sciences, Inc.

Environmental Strategies Corporation. 1990. Advance Process Supply Company, Pennsauken New Jersey, Additional Soil and Groundwater Investigations. Vienna, Virginia: Environmental Strategies Corporation.

Farlekas, G. M.; Nemicas B., and Gill, H. E. 1976. Geology and Ground-Water Resources of Camden County, New Jersey. U.S. Geological Survey Water-Resources Investigations Report. 76-76:146.

Faust, S. D., and Aly, O. M. 1981. *Chemistry of Natural Waters*. Ann Arbor, Michigan: Ann Arbor Science. 400 p.

Fusillo, T. V.; Hochreiter, J. J., and Lord, D. G. 1984. Water-Quality Data for the Potomac-Raritan-Magothy Aquifer System in Southwestern New Jersey, 1923-83. U.S. Geological Survey Open- File Report. 84-737: 127.

Geotech Environmental, Inc. 1990. Report on Remedial Investigation and Proposed Clean-Up Plan (ECRA case no. 87A82) Davidson P.W.P. Site, Pennsauken Township, New Jersey. Maple Shade, New Jersey: Geotech Environmental, Inc.

_____. 1991. Report on Supplementary Ground Water Remedial Investigation (ECRA case no. 87A82) Davidson P.W.P. Site, Pennsauken Township, New Jersey. Maple Shade, New Jersey: Geotech Environmental, Inc.

Gibs, Jacob; Szabo, Zoltan; Ivahnenko, Tamara, and Wilde, F. D. 2000. Change in Field Turbidity and Trace Element Concentrations During Well Purging. *Ground Water*. 38(4):577-588.

Henderson, Thomas. 1994. Geochemical Reduction of Hexavalent Chromium in the Trinity Sand Aquifer. *Ground Water*. 32(3):477-486.

Hoekstra, E. J.; De Leer, E. W. B.; and Brinkman, U. A. T. 1998. Natural formation of chloroform and brominated trihalomethanes in soil. *Environmental Science and Technology*. v. 32: 3724-3729.

Horowitz, A. J.; Demas, C. R.; Fitzgerald, K. K.; Miller, T. L., and Rickert, D. A. 1994. U.S. Geological Survey Protocol for the Collection and Processing of Surface-Water Samples for the Subsequent Determination of Inorganic Constituents in Filtered Water. U.S. Geological Survey Open-File Report. 94-539:57.

James C. Anderson Associates, Inc. 1988. Ground Water Investigation, Pennsauken Sanitary Landfill Site, Pennsauken, New Jersey. Mt. Laurel, New Jersey: James C. Anderson Associates, Inc.

_____. 1991. Letter from W.H. Matulewicz to Dick Walker/John Rhodes of Rhodes Engineering, July 9, 1991. Written communication.

_____. 1996. Maps prepared for the Township of Pennsauken. Mt. Laurel, New Jersey. John G. Reutter Associates. 1982. Hydrogeologic and Groundwater Quality Evaluation. Camden, New Jersey: John G. Reutter Associates. Prepared for SGL/Modern Hard Chrome Service Company, Pennsauken, New Jersey.

_____. 1983. Addendum to Hydrogeologic and Groundwater Quality Evaluation, September 1982. Camden, New Jersey: John G. Reutter Associates. Prepared for SGL/Modern Hard Chrome Service Company, Pennsauken, New Jersey.

Koterba, M. T.; Wilde, F. D., and Lapham, W. 1995. Ground-water Data-Collection Protocols and Procedures for the National Water-Quality Assessment Program: Collection and Documentation of Water-Quality Samples and Related Data. U.S. Geological Survey Open-File Report. 95-0399: 113.

Lacombe, P. J. and Rosman, R. 1997. Water Levels in, Extent of Freshwater in, and Water Withdrawn from Eight Major Confined Aquifers, New Jersey Coastal Plain, 1993. U.S. Geological Survey Water-Resources Investigations Report . 96-4206: 8.

Lockheed Martin. 2000. Field Activities, Soil and Soil Gas Sampling, Puchack Well Field Site, Pennsauken, New Jersey. Edison, New Jersey: REAC, Lockheed Martin Technology Services Group. Report prepared for the U. S. EPA, Environmental Response Team.

Markley, Marco. 1966. Soil Survey of Camden County, New Jersey, Series 1961. U.S. Department of Agriculture, Soil Conservation Service. 42(94), 34 pl.

Moore, J. W., and Ramamoorthy, S. 1984. *Heavy metals in natural waters*. New York, New York: Springer-Verlag. 268 p.

Navoy, A. S. and Carleton, G. B. 1995. Ground-Water Flow and Future Conditions in the Potomac-Raritan-Magothy Aquifer System, Camden Area, New Jersey. Geological Survey Report GSR 38:184. New Jersey Geological Survey.

NJDEP. 1990a. Robert A. Gallagher, February 1990, written communication.

NJDEP. 1990b. Dan Maltese, HSMS IV, NJDEP, DHWM, BPA, November 30, 1990. Report on SGL Modern hard Chrome Service, 482 Cove Road, Pennsauken Township, Camden County, New Jersey EPA ID # NJD002356475

_____. 2002. Watershed Management Area 18, Lower Delaware.
<http://www.state.nj.us/dep/watershedmgt/lowerdelaware.htm#wma18>

Owens, J. P. and Denny, C. S. 1979. Upper Cenozoic Deposits of the Central Delmarva Peninsula, Maryland and Delaware. U.S. Geological Survey Professional Paper 1067-A:27.

Owens, J. P. and Minard, J. P. 1979. Upper Cenozoic Sediments of the Lower Delaware Valley and the Northern Delmarva Peninsula, New Jersey, Pennsylvania, Delaware, and Maryland. U.S. Geological Survey Professional Paper 1067-D: 47.

Owens, J. P. and Sohl, N. F. 1969. Shelf and Deltaic Paleoenvironments in the Cretaceous-Tertiary Formations of the New Jersey Coastal Plain. In: *Geology of Selected Areas in New Jersey and Eastern Pennsylvania and Guidebook of Excursions*.

Edited by Seymour Subitsky. New Brunswick, New Jersey: Rutgers University Press. 235-278.
Palmer, C.D. and Puls, R.W. 1994. Natural Attenuation of Hexavalent Chromium in Groundwater and Soils. In: *EPA Ground Water Issue*. EPA/540/5-94/505:1-12.

Pankow, J. F.; Luo, Wentai; Isabelle, L.M.; Bender, D.A., and Baker, R.J. 1998. Determination of a Wide Range of Volatile Organic Compounds in Ambient Air Using Multisorbent Adsorption/Thermal Desorption and Gas Chromatography/Mass Spectrometry. *Analytical Chemistry*. 70(24):5213-5221.

Pennsylvania 2002. Pennsylvania State Climatologist, Philadelphia Local Climatological Data, May 20, 2002. <http://pasc.met.psu.edu/cgi-bin/lcdclim.cgi>.

Pettine, Maurizio; Campanella, Luigi; and Millero, F. J. 2002. Reduction of hexavalent chromium by H₂O₂ in acidic solutions. *Environmental Science and Technology*. v. 36 (5): 901-907.

Rhodes Engineering. 1990. Groundwater Sampling Results, ECRA Case No. 86819 for King Arthur, Inc., 965 Bethel Avenue, Pennsauken, New Jersey. Haddonfield, New Jersey: Rhodes Engineering.

Stablex-Reutter, Inc. 1982. Letter from W.J. Ziegler to Bernard McKenna of SGL Modern Hard Chrome, August 27, 1982. Written communication.

_____. 1984. Initial ECRA Notice Submission, Combined General Information Submission, and Site Evaluation Submission, SL Modern Hard Chrome Service, Pennsauken, New Jersey. Cherry Hill, New Jersey: Stablex-Reutter, Inc.

Seaman, J. C., Bertsch, P. M., and Schwallie, L. 1999. In situ Cr (VI) reduction within coarse textured, oxide-coated soil and aquifer systems using Fe (II) solutions. *Environmental Science and Technology*. v. 33: 938-944.

Stollenwerk, K. G., and Grove, D. B., 1985, Adsorption and desorption of hexavalent chromium in an alluvial aquifer near Telluride, Colorado: *Journal of Environmental Quality*, v. 14, no. 1, p. 150-155.

U.S. Environmental Protection Agency. 1983 (and subsequent revisions). Methods for Chemical Analysis of Water and Wastes. Washington DC: U.S. Environmental Protection Agency. EPA- 600/4-79-020.

_____. 1986a. Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. Washington DC: EPA 530/SW-846, Third edition and subsequent updates.

_____. 1986b. Superfund Public Health Evaluation Manual. Washington, D. C.: Office of Emergency and Remedial Response, Office of Solid Waste and Emergency Response. OSWER Directive 9285.4-1. EPA/540/1-86/060. October 1986.

_____. 1996. Soil Screening Guidance: User's Guide 2nd Edition. Washington, DC: Office of Solid Waste and Emergency Response. EPA/540/R-96/018. July 1996

_____. 1997. Methods and Guidance for Analysis of Water. Washington DC: EPA-821-C-97-001.

_____. 2000a. Environmental Justice Demographic Profile for Puchack Well Field, March 8, 2002. http://oaspub.epa.gov/enviro/ej_dem_profile?fac_uin=NJD981084767

_____. 2000b. In Situ Treatment of Soil and Groundwater Contaminated with Chromium: Technical Resource Guide. Cincinnati, Ohio: Department of Research and Development. EPA/625/R-00/005.

U.S. Geological Survey. 2000. Final QAPP for the USGS Field Data Collection. West Trenton, New Jersey: U.S. Geological Survey.

Walker, R. L., and Jacobsen, Eric. In press. Reconnaissance of Hydrogeology and Groundwater Quality in Pennsauken Township and Vicinity, Camden County, New Jersey, 1996-1998. West Trenton, New Jersey: United States Geological Survey.

Weston.1997. Hazard Ranking System Documentation Package, Puchack Well Field, Pennsauken Township, Camden County, New Jersey. West Chester, Pennsylvania: Roy F. Weston, Inc. Prepared for the United States Environmental Protection Agency.

Wiedemeir, T. H.; Swanson, M. A.; Moutoux, D. E.; Gordon, E. K.; Wilson, J. T.; Wilson, B. H.; Kampbell, D. H.; Haas, P. E.; Miller, R. N.; Hansen, J. E., and Chapelle, F. H.1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water. Washington DC: U.S. Environmental Protection Agency, Office of Research and Development. EPA/600/R-98/128.

Zapeczka, O. S.1989. Hydrogeologic Framework of the New Jersey Coastal Plain. U.S. Geological Survey Professional Paper. 1404-B:49, 24 pl.